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PROCEEDINGS OF THE TENTH
SOUTHERN CONFERENCE ON FOREST TREE IMPROVEMENT
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Thurman E. Bercaw
(1914 – 1969)

These Proceedings are dedicated to Thurman E. ("Ted" or "Berc") Bercaw. Berc's death in a crossing accident at Livingston, Louisiana, on June 2, deprived his company and his profession of a singularly able man, and the Southern Forest Tree Improvement Committee of a charter member whose contributions were outstanding.

Berc was born in Columbus, Ohio, November 26, 1914. He obtained the B.S. in Forestry at the University of Michigan in 1938, with subsequent work there and at Harvard in forest photogrammetry and photo interpretation. From 1940 to 1946 he served in the U.S. Army Air Corps, attaining the rank of Major, and after the War became a Colonel in the Air Force Reserve. After various Federal and State jobs before and after the War, he came to Gaylord Container Corporation (later merged with Crown Zellerbach Corporation) in September 1946, serving successively as Management Forester, Head of the Forest Management Section, and Head of the Research and Inventory Section. A scant two months before his death he was promoted to the position of Chief Forester of Crown Zellerbach's Southern Timber Operations. He was active in numerous professional, civic, and trade associations; perhaps his most notable professional appointment was to the U.S. Department of Agriculture's Forestry Research Advisory Council, on which he served with great effect for several years.

I first met Berc in November 1947 on a memorable tour of the Southern Forest Experiment Station's planting and brown-spot-control experiments at Bogalusa, Louisiana, and an inspection of damage by the September hurricane to Gaylord Container's 17-year-old, rust-infected, planted slash pine. From then on until my own retirement in 1964 he and I shared data and ideas on tree diseases and artificial regeneration. In the mid-Fifties he contributed the services of his highly skilled continuous-inventory crews to the 30-year remeasurement of some 20,000 trees in the Southern Station's oldest experimental plantations and helped me set up the computer analysis of the results. He and I "cut our teeth together," so to speak, on forest genetics when, in 1951, we were both appointed to the newly formed Committee on Southern Forest Tree Improvement. As Head of Gaylord Container's Forest Management Section he unhesitatingly engineered, in 1952-53, the largest single installation in the Committee's Southwide Pine Seed Source Study.

A big, brilliant, versatile, breezy, rollicking man, Berc galvanized every enterprise in which he took part. Clear-headed boldness and decisiveness always seemed to me his outstanding personal and professional characteristics. He was quick to perceive the essence of a problem, and prompt, imaginative, and thorough in handling it. Work with him was a pleasure as well as an inspiration, and many beside myself will miss him as a forester and as a friend.

Philip C. Wakeley

Philip C. Wakeley
U.S. Forest Service, Retired

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KEYNOTE ADDRESS

Physiological Limitations of Productivity

Dr. C.H. van Bavel
Professor of Biology
Texas A&M University

PHYSIOLOGICAL LIMITATIONS OF PRODUCTIVITY

C. H. M. van Bavel [1/]

The crop breeder who attempts to increase economic yield potential traditionally proceeds in an empirical fashion. This approach has worked well in the past, but it has its obvious drawbacks. First, it is slow, particularly in the case of tree crops, and, second, the results are not necessarily general. That is to say, the yield of a crop is as much a reflection of its genetic make-up as it is of the environment in which it grew.

By attempting to isolate specific attributes that control productivity we may hasten the selection process and make the results more generally valid. But, in fairness to crop breeders, it must be recorded that neither crop physiologists nor crop ecologists have set out specific goals for breeders to attain.

We will indicate here two principal aspects of productivity in which both environment and crop interact to result in a physiological ceiling of performance. The first is light utilization in photosynthesis and the second is the water balance.

Light Utilization

A given site is characterized by a given photosynthetic light climate as measured by the spectrally distributed radiant energy per unit horizontal surface and per unit time (day, month, year) in the wave band from 0.4 to 0.7 microns. On the basis of present knowledge, there is no important difference in the effectiveness for photosynthesis of light within this broad band (Federer and Tanner, 1966). There is some difference in light absorption in that the green light is absorbed less than the other colors, giving foliage its color, both in reflected and transmitted light. Again, within the 0.4 to 0.7 micron waveband, the spectral composition of natural light does not vary greatly. We can, therefore, measure the "plantwatts" per square meter or PAR (photosynthetically active irradiance), in first approximation, with a standard pyranometer with a heat absorbing filter that cuts off at 0.4 and 0.7 microns, (McCree, 1966). Sometimes, a standard fraction of the total measured short wave radiation (0.3 - 2.3 microns) is used to arrive at PAR but this is a much worse approximation.

The question is what use the crop canopy can make of the incident radiant flux so defined and measured. First of all, this is a physical problem in light interception and it is laid out in terms of sun angle, leaf angle, leaf area index, and other geometrical and morphological characteristics of the canopy. The calculations become very complicated and solutions can be found only by computer simulation.

1/ Institute of Life Science
Texas A&M University, College Station, Texas 77843

So far, work of this sort has been done for broadleaved canopies only and it has given us some insight into the optimum morphology of plant stands (Duncan, et.al., 1967). No efforts have been made to deal in the same way with canopies of needle-shaped leaves.

The fate of intercepted light depends upon radiative properties of foliage. It remains yet to be seen whether there are significant differences between species and within progenies in a breeding program, that could be the basis of selection.

Finally, the utilization efficiency of absorbed light in photosynthesis may also vary as the result of differences in internal leaf structure or in biochemical factors. Experimentally, the two categories of effects are lumped together when we measure the CO_2 fixation rates of individual leaves as affected by varying levels of incident light.

It appears that a consideration of the growth habits of trees in regard to leaf angle, leaf area index distribution, leaf size and shape is one parameter that deserves study and could be the basis of rational selections.

Another possible useful parameter is the "light-saturation" curve of individual leaves at standard levels of carbon dioxide concentration and at standard leaf temperatures.

Water Balance

The potential of a leaf array in a given light environment for photosynthesis and growth can only be realized when a favorable water balance in the leaf exists. The explanation of adverse effects of water deficits upon photosynthesis is not fully established (Slatyer, 1967), but at least a partial explanation resides in the closure of leaf stomata that results from a decrease in water potential and water content. Regardless of cause, the necessity for minimizing water deficits calls attention to at least three physiological factors with physical significance.

First, we must consider the nature of root systems. The leaf water potential is always lower than the root water potential and the latter is lower than that of the soil water potential by the following amount (Gardner, 1960):

$$\Delta \psi = \frac{E}{4 \pi d K L} \ln (1/ \pi L r^2)$$

E is the rate of water use by the canopy and L the root density in cm^{-2}. Further, d is the depth of the rooting zone, K the hydraulic conductivity of the soil and r the root radius. The important thing about this equation is that it shows how the potential drop involved in water transfer from soil to root is directly related to both depth and density of rooting. The product dL could be called a root proliferation index and it could well be an important basis for early selection.

Second, an additional drop in water potential is represented by the translocation of water from root to leaf. The conductivity of stems or trunks for water is considerable and Scholander (1965) has demonstrated in certain cases that the potential drop can be accounted for on the basis of elevation alone. This may not be so always and further studies should be made of the role of the distance between leaf and root on leaf water potential. It may turn out that tall trees are not the most efficient ones, in part because of the adverse effect of height upon leaf water balance. Such a consideration would have an important inference for selection.

Thirdly, the depression of leaf water potential relative to the potential of soil water is directly proportional to the actual rate of water loss, or the transpiration. This parameter is, in part, controlled physiologically through the stomata in the following way (see Van Bavel, 1967).

$$E_a = E_o \, (\varepsilon + 1)/(\varepsilon + 1 + r_s \, C_d \, u)$$

E_o is the potential or maximum possible water loss, determined by the weather. E_a is the actual water loss, ε a number dependent upon temperature, C_d a crop constant (drag coefficient) and u the windspeed. The role of the stomata is in the factor r_s, which, in first approximation, can be equated to:

$$r_l \; / \; \text{LAI}$$

the leaf resistance divided by the leaf area index. In turn, r_l is determined by the number of stomata per unit leaf area, and the length and hydraulic radius of the individual stomata. On broad leaves r_l can be readily measured (Van Bavel, et.al., 1965).

It can thus be seen that water use can be regulated by stomatal morphology and physiology. Decrease in water use results in maintenance of leaf water balance at a higher level.

At the same time, stomatal aperture influences CO_2 entry and photosynthesis. The optimum value for the parameter r_s and r_l can only be determined by direct experimentation on the water use efficiency of individual leaves and leaf arrays. When properly carried out such studies could be a valuable tool in selection of promising strains. In such tests it is essential that the environment be known, controlled and realistic. Currently available environment chambers leave much to be desired with regard to the light factor and the control over CO_2 concentrations.

Conclusion

Only two important aspects of plant foliage and of canopies that control plant productivity have been discussed. These characteristics of the plant cover can be specifically identified and measured in a physically justified way. These traits may be useful as criteria in the selection of high-yielding strains in a breeding program, but not enough work has been done to assure the breeder of success in this way.

There are certainly very special problems when trying to measure the physical properties of needle-like leaves. Light climate studies under canopies of needles (Logan and Peterson, 1964) are not sufficient; we must know why and how such climates come about. Also, the light must be measured in a physiologically meaningful way. But, apart from this, modeling of light interception and light utilization by needle canopies is going to be difficult.

There are indications (Szeicz, et.al., 1969) that in a pine forest the role of stomata in water loss is dominant over other foliage parameters. To what extent this applies to CO_2 exchange is an open question. Controlled studies of water use efficiency in needle canopies and the variation between species and strains appear an appropriate field of research that could give direction to the efforts of breeders.

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SESSION I

First and Second Generation Selection

Moderator: J. W. Wright

From left to right: J. P. van Buijtenen, Walter R. Beineke, Roy Stonecypher, J. W. Wright, K. A. Taft

RECURRENT SELECTION IN FOREST TREE BREEDING

BY

ROY W. STONECYPHER[1/]

INTRODUCTION

The rapid development of applied tree breeding programs in the South has concentrated much of our earlier work on problems related to selection and establishment of sources for the production of improved seed. It seems appropriate, now that many of the original goals have been reached, that our attention should turn to thoughts of further cycles of selection in tree breeding programs.

This paper will discuss the use of recurrent selection in crop breeding programs and relate this use to tree breeding. It should be pointed out in making a comparison between crop and tree breeding programs, however, that in the latter the commercial production of seed has been customarily considered as an inseparable portion of the breeding program. While the goal of the crop breeder is like the tree breeder commercial production of improved material,in many crop plants the breeding program is considered somewhat apart from the commercial production of seed. It would appear that such a separation might have merit in certain tree breeding programs and will probably evolve as subsequent generations of select material become available.

While it is not the purpose of this paper to present all-inclusive details of breeding procedures available to the tree breeder, it is hoped that the paper will be useful in providing a coherent framework within which the breeder can operate.

Classification of Breeding Systems

Classification of plant breeding systems has been traditionally based on methods of reproduction. The three major categories are: Self-Pollinated, Cross-Pollinated, and Asexually-Propagated.

Sprague (1967) has provided an alternate classification of breeding systems by use of the terms "population improvement" and "hybridization." As defined by Sprague, population improvement includes all operations within a system designed to yield a sexually-propagated improved type whether this be a random mating population or pure line. Hybridization, on the other hand, was defined to include all aspects of a system designed for the commercial production of F_1 hybrid seed.

1/ Senior Research Forester, International Paper Company, Southlands Experiment Forest, Bainbridge, Georgia.

Note that the above definition of population improvement does not include the use of asexual reproduction. Since, however, continued improvement of vegetatively propagated material generally involves the use of sexual reproduction, the production of vegetatively propagated material resembles the development of pure lines. The difference lies in the fact that genetic homozygosity if not required for the mass production of desirable genotypes which can be vegetatively propagated.

Sprague's system of classification appears to have merit for categorizing tree breeding programs. Drawing heavily on quantitative genetic principles, and providing a framework within which tree breeding systems can logically be included, the two categories seem to be well adapted to classifying forest tree breeding programs.

Recurrent Selection Defined

The term recurrent selection was first used by Hull (1945). According to Hull (1952), "recurrent selection was meant to include re-selection generation after generation, with interbreeding of selects to provide for genetic recombinations." Note that, in applying the above definition to a selection program, the program is not recurrent until the selects have been interbred and a new cycle is initiated. Non-recurrent selection programs have been referred to as "pick the winner" selection (Cockerham, 1961).

RECURRENT SELECTION IN BREEDING PRACTICE

The interest in recurrent selection first arose in maize breeding programs because of general disappointment with the performancies of second-cycle hybrids (Hull, 1952).

As Penny et al. (1963) have pointed out, recurrent selection is a method for improving populations where the ultimate goal is the development of a superior population for commercial production. In addition, it is also a means for developing commercial hybrids. In fact, recurrent selection programs were first suggested as a means for developing improved inbred lines for the production of hybrids in maize.

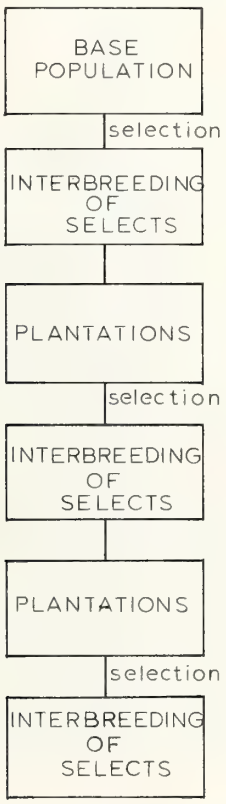
It would appear that recurrent selection is receiving more emphasis in forest tree breeding from the stand point of developing superior populations for commercial production per se. Although much hybridization work has been carried on in forest genetics work, a relatively small amount of this crossing has involved systematic selection or testing of the parents which were involved in the production of these hybrids. Such an oversight is most unfortunate.

The developments which follow in this paper are concentrated on the use of recurrent selection as a method for producing improved populations. The use of this breeding system, however, should not be overlooked as a means for producing potentially valuable racial or species hybrids from existing selected forest tree material.

Theoretically, recurrent selection is a breeding procedure for increasing the frequency of desirable genes within a population while maintaining sufficient variability for continued selection (Penny et al., 1963). The importance of such considerations to tree breeding programs is obvious.

Phenotypic Recurrent Selection

Phenotypic recurrent selection is defined as recurrent selection in which the phenotype of the individual plant serves as the basis for selection (Penny et al., 1963). Such a system is shown in Figure 1.



PHENOTYPIC RECURRENT SELECTION

Figure 1. Diagrammatic representation of phenotypic recurrent selection. Note that the selections for a given cycle are recombined and are the base for the next cycle.

An example of phenotypic recurrent selection in forest tree breeding would be selection of trees in the forest followed by interbreeding of selects with subsequent selection and interbreeding of selects from the first generation. (See Figure 1)

Genotypic Recurrent Selection

Genotypic recurrent selection will be assumed to include types of recurrent selection in which identity of families is possible; i.e., a system of matings is used to develop relatives (Figure 2). The important distinction between phenotypic and genotypic selection is that in the latter additional information from phenotypic values of relatives often provides a more reliable guide to the breeding value of an individual than the phenotypic values alone (Falconer, 1960).

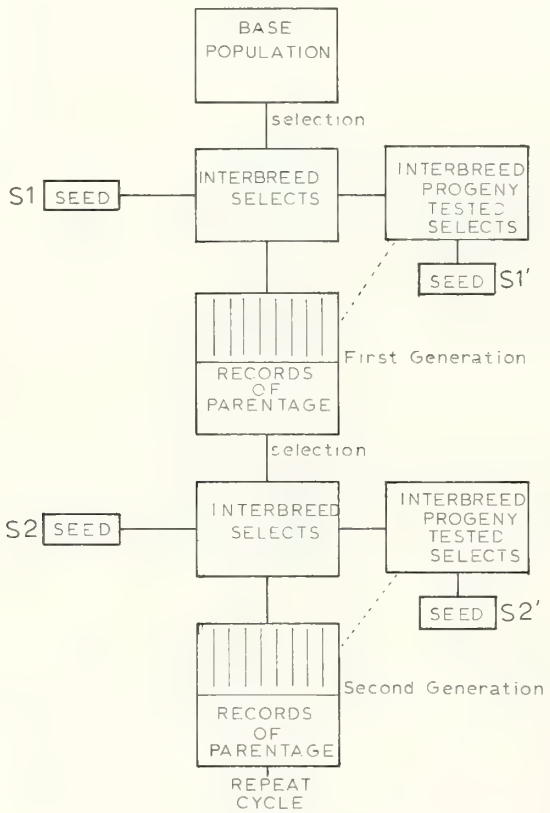


Figure 2. Diagrammatic representation of genotypic recurrent selection. Records of parentage are required and selections can be based on performance of relatives.

RESULTS OF RECURRENT SELECTION STUDIES

As indicated earlier, recurrent selection procedures were initially developed in an attempt to produce superior inbred lines for the production of hybrid maize. Of more general interest to tree breeders at present, however, are the results from crop studies which can be applied to the goal of developing superior populations for commercial production.

In Crop Plants

One of the earliest studies on the effectiveness of phenotypic recurrent selection was that of Sprague and Brimhall (1950) for increased oil percentage in maize. The mean oil percentage was shifted rapidly upward through the second-cycle of the series. A similar result was obtained by Jenkins et al. (1954) in selection for resistance to a leaf blight of maize. It should be emphasized, however, that phenotypic recurrent selection has generally not been effective in breeding for improved yield in crops (Allard, 1960).

Of the types of genotypic recurrent selection, data from studies involving recurrent selection for general combining ability are more numerous. Lonnquist and McGill (1956) concluded that improvement in yield and general economic worth was achieved in two cycles of recurrent selection for general combining ability in three synthetic varieties of corn. A synthetic variety is defined by Allard (1960) as a variety produced by crossing inter se a number of genotypes selected for good combining ability in all possible combinations with subsequent maintenance by open-pollination. In alfalfa, Tysdal and Crandall (1948) concluded that clones selected for high general combining ability produced a synthetic variety having a higher yield than standard varieties.

Several additional examples of the effectiveness of recurrent selection for general combining ability are available. In general, this procedure has been successful in producing improved types, particularly in forage crops.

Data from studies using recurrent selection for specific combining ability and reciprocal recurrent selection are scanty (See Sprague, 1967). In general, studies of these two types of recurrent selection are being carried out for evaluations of their efficiency in hybridization programs.

In Forest Trees

Data from specific recurrent selection studies in forest trees are not presently available. There are, however, data available from various sources which can be used to estimate the degree of improvement from use of recurrent selection.

Indication of improvement from first generation selections in tree improvement programs are beginning to accumulate. Marler (1963) presented a summary of estimates of gains which have been obtained by various workers. Reports to date have indicated that gains of 10 to 15 percent more volume than commercial checks have been attained in southern pine programs.

Estimates of realized gains from second generation selection unfortunately are not available. Estimates of genetic variances have been obtained for tree populations, however, and these estimates can be used to predict gains expected in the second cycle of selection. An example of the use of such estimates is presented below.

AN EXAMPLE OF RECURRENT SELECTION IN FOREST TREE BREEDING

The data for this example were taken from three year total heights of a pollen mix test of 22 slash pine clones (Pinus elliottii Engelm) and 2 commercial checks of International Paper Company's Gateswood Seed Orchard in the Gulf Woodlands Region. The test involved 12 tree row plots planted in 4 replications on each of 2 locations.

Realized gain in total height of the select progenies was nine percent of the mean of the commercial source. This difference between the selects and commercial check was significant at the five percent level.

In order to predict gains expected from second cycle selection in this population, genetic and environmental variances were estimated from an analysis of the progeny of the selected clones only.

Gains in three year total height were estimated using the formulae developed by Namkoong et al. (1966) and are presented in Figure 3 as percent of the means of the selects and in Figure 4 as hundredths of feet.

Two selection methods were compared in Figures 3 and 4. In the combined selection procedure the best half-sib families are chosen and the best individual or individuals within these families is selected. Such a procedure would lead to the production of the S2 seed of Figure 2. Progeny test selection involves the selection of desirable parents based on the performance of their offspring. The first cycle of this system would lead to the production of the S1' seed of Figure 2.

Figure 3 compares these two selection procedures in terms of predicted gain in percent of the mean of all the select progenies. As can be seen from Figure 3, the predicted gain using the combined selection procedure is over double the gain of the progeny test procedure when the number saved is 12 or over. It would appear that, because of practical considerations related to seed production, the number of clones saved in a progeny tested orchard would be at least half of the original selections.

The comparisons of the selection procedures of Figure 3 should not be construed as an argument against progeny testing per se. What these graphs do point out is the importance of considering the progenies themselves as the basis for the next cycle of selection.

In Figure 4, comparisons of the methods are based on gain per unit time. In constructing this graph, the gain was divided by the estimated time in years to produce seed from each of the methods. It was assumed that the progeny would be evaluated at 10 years of age at which time the seed orchard would be rogued and the benefits of this roguing would occur two years later in the S1' seed of Figure 2. The combined selection gain figures were estimated by assuming the progenies would produce seed in commercial quantities at 10 and 20 years after initial assessment at age 10.

The comparisons in Figure 4 clearly show the importance of considering the progenies as a base for the next cycle of selection. Note that even in the case where 30 years for seed production was assumed for the combined selection procedure the gain per unit time gain estimates closely approached progeny test gains at a number saved of 14, and exceeded progeny test gain at numbers saved of 16 and over.

The example developed above is related to a testing procedure using a pollen mix, i.e. only one parent is known. Recurrent selection based on such a mating design with the limited number of clones (22) used in this example would lead to excessive inbreeding. Such inbreeding can be minimized by including more clones in the program and/or by using mating designs in which both parents are known.

The above examples were presented to emphasize the importance of considering the progenies of selected trees as the base for subsequent cycles of selection. It should be recognized that these examples are simplified in that the breeding system was considered closed. In actual practice this will normally not be the case as new selections at various stages of testing will enter the program. This, of course, will further tend to minimize inbreeding.

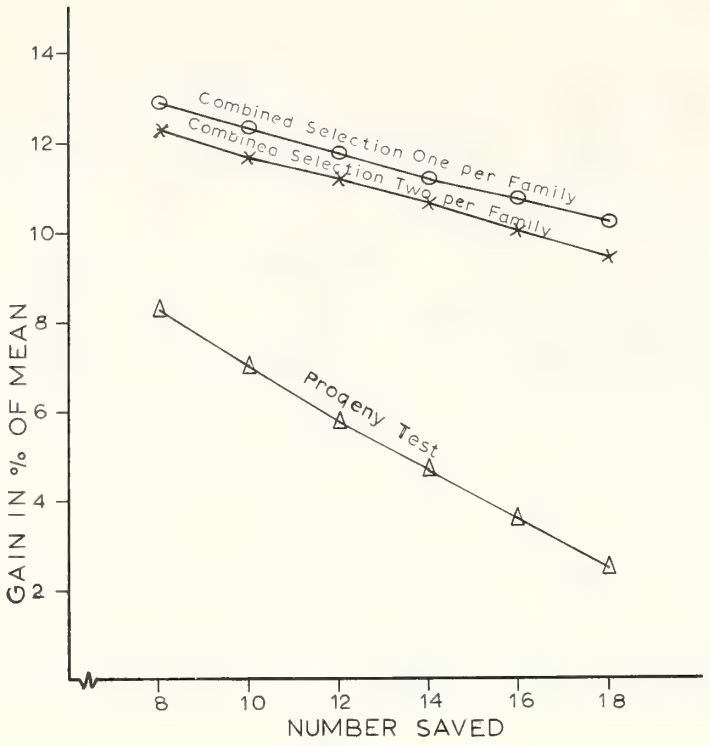


Figure 3. Comparison of two methods of recurrent selection in terms of gain in percent of the mean of the selects. Number saved is based on a total of 22 clones and refers to clones saved in the case of progeny testing and families saved in the case of combined selection.

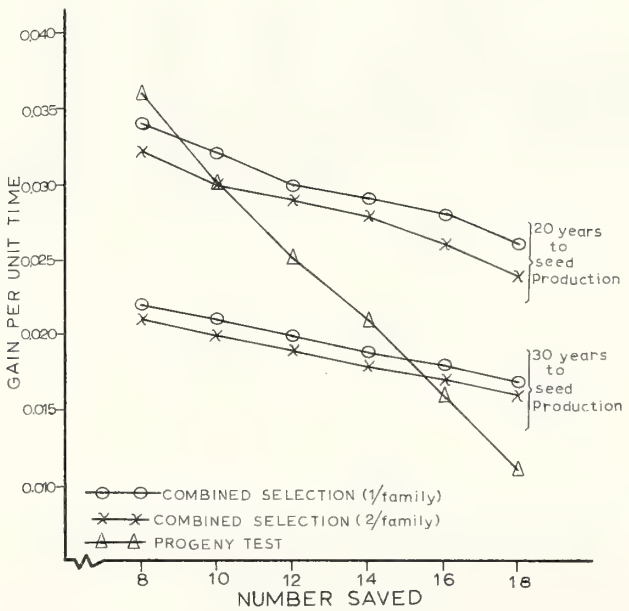


Figure 4. Comparison of two methods of recurrent selection in terms of gain per unit time. Note where combined selection lines intersect progeny test line.

SUMMARY

This paper has attempted a brief discussion of recurrent selection, its use in crop breeding, and its importance to tree breeding.

Recurrent selection implies that the selected material from a given cycle is recombined to serve as the base for the next cycle. Thus, in the example discussed in this paper both the progeny test and combined selection are types of recurrent selection.

The comparisons of the two systems in the example used pointed out the importance of considering the progeny themselves as a base for repeated cycles of selection in an applied tree breeding program.

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PROGRESS AND PROBLEMS IN FOREST TREE SELECTION

By

J. P. van Buijtenen [1/]

INTRODUCTION

The following paper will be limited to forest tree selection in the southern United States, keeping the discussion within the framework of this meeting. Although most of the forest tree improvement work in the South has been done with pines, the discussion will not be restricted to them but will include hardwood species as well, which present many problems of their own. Since Dr. Stonecypher covered the topic of second-generation selection thoroughly, I will concentrate on first-generation selection.

OBJECTIVES OF SELECTION

Although selection objectives may differ in detail as much as the people doing the selecting, they can be grouped roughly into two categories: increase in the quantity of wood produced and improvement of its quality.

For a given age and number of stems per acre quantity production is largely controlled by the following characters: height, DBH, form class, and wood specific gravity. Here already a divergence of viewpoints exists. To the producer of lumber and plywood, volume is the most significant measure of quantity; wood specific gravity is primarily a quality factor, affecting such properties as strength, shrinkage, and adhesiveness. To the pulp and papermaker, however, specific gravity has both quantity and quality components, affecting pulp yield and fiber wall thickness, and therefore other properties, such as tear factor, tensile strength, bursting strength, refining energy in groundwood production, and so on. There are many other properties which in a similar way affect both quantity and quality: natural pruning, stem form, branch habit, fiber wall thickness, fiber length, amount of compression wood, and summerwood content.

Where quality is concerned, selection objectives may differ widely from organization to organization. With the advent of stress grading a lumber mill may be very much interested in an increase in specific gravity, while at the same time a groundwood mill may be primarily interested in wood of low specific gravity, resulting in reduced refining energy and better pulp and papermaking properties.

METHODS OF SELECTION

The rating systems currently being used in the South for superior tree selection can be grouped under three headings. The method of selecting pines most commonly accepted in the South is by means of a rating system based

1/ Principal Geneticist, Texas Forest Service, and Associate Professor, Texas A&M University, College Station, Texas.

on a comparison of the selected tree with a number, usually five, of the best dominant trees within the vicinity. Vicinity is defined fairly loosely, but may include as much as a one-acre plot with the selected tree at the center. The selected tree is given a point score for individual characters based on its superiority over the comparison trees. An example of such a point score is given in Table I.

TABLE I

EXAMPLE OF POINT SCORE ON LOBLOLLY PINES [1]

	Score	
	Minimum	Maximum
Height	0	15
Volume	0	7
Crown	-2	5
Form point	-3	3
Straightness	0	5
Pruning ability	-3	3
Branch diameter	-2	2
Branch angle	-2	2
Specific gravity	-2	10
Age	0	3
Total possible points		55

1) Scoring system used by International Paper Company.

This method is satisfactory in plantations and even-aged natural stands but loses most of its value in uneven-aged stands. In contrast to the method discussed below, no measure of selection intensity is obtained, since the check trees themselves are considerably above the average of the stand.

Another system in use can be called a base-line or regression system. It requires considerable knowledge of the growth of a given species on the sites where it is usually found, and consists of predicting the range of values to be expected of a given species on a given site and rating the selected tree against these values. In this case it can be rated as a certain percentage or a certain number of standard deviations above the average. The system is applicable under most stand conditions, but may be subject to more error than the comparison tree system.

The method of selection is always dependent on the biology of the species selected and should be developed with this in mind. A case in point is the selection of hardwoods. Many of these are extremely different from pines, and the selection system developed for pines simply cannot be adopted uncritically. To give an extreme example: selecting quaking aspen or sweetgum by the comparison system would be meaningless, since both frequently occur in clones. Since all trees in a clone would be of the same genetic constitution, the difference between the selected trees and the check trees could be entirely a reflection of the environment.

Many hardwoods are found in uneven-aged stands. As a consequence they have to be graded against absolute standards rather than on the basis of a comparison with check trees. An example of such a scoring system is given in Table II.

TABLE II

EXAMPLES OF POINT SCORE ON HARDWOODS

(Developed by R. Farmer for selection of cherrybark oak)

	Score	
	Minimum	Maximum
Straightness	0	5
Crown	0	5
Epicormic sprouting	-3	3
Pruning ability	-3	3
Branch angle	0	2
Leader dominance	0	5
Total possible points		23

MULTIPLE TRAIT SELECTION

Because of the long generation span in forest trees, it is not practical to improve only one trait in one generation. Instead, it becomes desirable to improve several traits simultaneously. One approach to so doing is to select for each trait individually. As the number of traits increases it becomes of course increasingly difficult to find the type of tree desired. Selecting for instance, the best tree out of one hundred for each trait, and assuming no correlation between traits we would find one out of a hundred for one trait, one out of ten thousand for two, one out of a million for three traits, and one out of a thousand billion for six traits. This last figure somewhat exceeds the number of trees available.

Another approach is to weight each character by a score depending on its inheritance and economic value and to select the trees with the highest score. Theoretically this is the most efficient approach, although in practice it leaves something to be desired. The index could be used in conjunction with the comparison tree system or with a base-line system, where a tree's selection index would have to exceed a certain value to be accepted. Two examples are given in Table III.

The comparison tree system of selection is somewhat of a combination of a true selection index and selection using independent culling levels, with a point score being given to a tree for various characteristics, while at the same time the selected tree does have to meet certain minimum criteria of freedom from disease and insects, of form, and in some cases of specific gravity.

TABLE III

EXAMPLES OF SELECTION INDEX[1)]

EXAMPLE ONE

Selection index = .6 X height + 2.5 X DBH - 50 X s.g. - .2 sweep - .5 X[2)] crook + 1.3 X spiral - 2.6 X lean.

Range of Selection Index Scores if Calculated on the Basis of the Comparison Tree System

	Score	
	Minimum	Maximum
Height	0	10
Diameter	0	15
S.G.	-1	4
Sweep	-.5	.5
Crook	-.5	.5
Spiral	-2	2
Lean	-4	4
Total possible score		36

EXAMPLE TWO

Selection index = -1.4 X stemform + .67 dry weight (kg).

Range of Selection Index Scores if Calculated on the Basis of the Comparison Tree System.

	Score	
	Minimum	Maximum
Form	-4	4
Dry weight	0	20
Total possible score		24

1) Based on data obtained from 10-year-old open pollinated progeny test of loblolly pine.
2) Stem form, sweep, crook, spiral, and lean were rated on a 4-point scoring system, as follows:

1 = Superior tree quality
2 = Above average
3 = Below average
4 = Dismal

USE OF MATHEMATICAL PROGRAMMING

Another approach to tree selection, one which to my knowledge no one has tried so far, is the use of mathematical programming methods. Mathematical programming is used in many industries to optimize operations and might very well have application in this field. It is applicable in a situation where a number of limited resources have to be utilized to either minimize cost or maximize profit. In the case of tree improvement, for instance, one could define the manpower, land, and budget available, and then maximize the profit obtainable by selecting for certain characteristics. It is an extremely powerful method, one forcing a person to analyze his operations critically and to keep always in mind such matters as facilities, budget, manpower, and expected returns. A very simple hypothetical example is given in Table IV. Value produced is given in dollars per acre for each unit of selection. In this case a selection differential of one standard deviation is defined as the unit.

The constraints (limiting resources) are given in terms of man-years required to produce one unit of genetic improvement in volume or one unit of genetic improvement in wood specific gravity. The right-hand column gives the number of man-years available. The bottom row shows the limits put on the selection intensity to keep the model realistic.

The solution shows that maximum value production is obtained when laboratory and field personnel are fully occupied. It also shows that the grader and supervisor have extra time available and that the "production" is limited by the manpower available in the laboratory and in the field.

The model can be made extremely revealing by describing the system in more detail and in actual budget terms.

SELECTION FOR RESPONSE TO INTENSIVE CULTURE

In agriculture the experience has been that as much or more improvement is obtained by more intensive culture practices, resulting from the use of improved seed, as is obtained from the genetic improvement itself. We can expect the same thing to happen in forestry and many signs are indicating already that this is happening. Practices such as fertilization, bedding, and even irrigation, which were practically unheard of ten years ago, are being applied on varying scales right now. It is important therefore that in tree selection we take these changes into account and select for individuals which are capable of responding to intensive cultural practices. (Pritchett and Goddard, 1967). Early indications obtained on pines have been promising, but the greatest opportunities in this area are probably in hardwoods. Many of these species are inherently more demanding than pines and more capable of responding to high fertility levels.

PROGRESS OBTAINED BY SELECTION

Good data are becoming available on the inheritance of volume growth, height, DBH, and wood specific gravity. As a rule of thumb the lower herit-

TABLE IV

EXAMPLE OF MATHEMATICAL PROGRAMMING

Constraints		Volume	SG	Total
Type	Name			
N	Value	15.00	7.5	
L	Fieldwork	1.0	.2	2.0
L	Grader	.2	.05	1.0
L	Laboratory	.01	2.00	2.0
L	Supervision	.05	.01	.3
Bounds	Upper	3.0	3.0	
	Lower	1.5	.5	

Solution

Row	At	Activity	Slack Activity	Lower Limit	Upper Limit
Value	BS	34.46	-34.46	none	none
Field work	upper limit	2.0	--	none	2.0
Grader	BS	.41	.59	none	1.0
Lab. work	upper limit	2.0	--	none	2.0
Supervision	BS	.1	.2	none	.3

Column	At	Activity	Input Cost	Lower Limit	Upper Limit
Volume	BS	1.8	15.0	1.5	3.0
SG	BS	.99	7.5	.5	3.0

abilities are found in the more variable characteristics. Values reported in the literature and results obtained in the Texas Forest Service program indicate that the heritability of wood specific gravity may be around 50%, of height about 20%, of diameter around 15%. Since the increased variability compensates for the lower inheritance, the expected gain varies only moderately among characteristics and runs between ten to twenty percent in one cycle of selection. Branch size and amount of knotwood have been shown to be definitely inherited (van Wedel et al.,1967). Straightness and natural pruning show genetic differences, although it is much harder to put definite values on this, since they are rated by a scoring system rather than measured.

One of the most important benefits of genetic improvement is through the reduction of losses. Breeding for resistance to drought, rust, insects, and brown spot, for instance, offers good opportunity for improvement. This has already been borne out by considerable experimentation. (Jewell and Mallett, 1961; van Buijtenen, 1966).

Wood properties are also inherited to a considerable extent. The genetic gains to be expected are of the order of 10% in one generation of selection. For some properties, such as wood specific gravity, it is quite meaningful, for other properties, such as fiber length and fiber wall thickness, this may be small in comparison to modifications obtainable through technology. There is much data available on this subject, but the interpretation is not clear and the matter is under study at present by one of the sub-committees of the TAPPI Forest Biology Committee.

ANALYSIS OF RETURNS ON INVESTMENT

In considering the investment returns from tree improvement in detail one cannot completely separate the selection for various properties, but rather has to look at groups of related activities. I would like to single out a number of groups for somewhat closer consideration, specifically field selection, selection involving laboratory testing, selection involving tests that can be carried out at an early age in the nursery or a similar setting, and selection involving progeny testing under field conditions.

Field Selection

At this stage one can select for growth rate, stem form, crown form, and freedom from diseases and insect. The cost of selection at this level is dominated by two general principles. 1) The major cost is in locating a promising tree to start with. Once one has found a tree worth looking over in detail, the cost of checking additional traits is relatively small, so one might as well describe the tree as accurately as possible. 2) The more traits are considered the more difficult and therefore the more costly it is to find a tree which is acceptable in all respects. To keep cost down, one has to either limit the number of traits selected for or to allow excellence in one trait to compensate for a deficiency in another.

Present indications are that the improvement obtainable in quantity production alone is from 10% to 20%. It is impossible to make estimates of

increase in value through quality improvement without specifying particular products involved. Even for any given end product, one could do no more than make an educated guess.

Selection Involving Laboratory Testing

In this category we find mostly wood properties and chemical properties. At present it is clear that wood specific gravity can be improved by selection and that this can be done cheaply. The cost of determining the specific gravity on one sample runs somewhere around a dollar. The determination of other properties such as summerwood percent, fibril angle, fiber length, and fiber wall thickness is much more expensive. Somewhere in this region we are near the point where it would be as economical to improve the quality of the end product by technological means as it is to improve them by genetic means. This is, however, no more than a guess and urgently needs to be studied in depth.

Selection Involving Early Testing of Progenies

In this category fall testing for disease resistance and testing for drought resistance. In both cases the gains to be made are considerable and can be obtained quickly. In the case of resistance to fusiform rust, it may mean an increase in productivity of 25% or more. In the case of resistance to brown spot or drought resistance, it may mean the difference between being able to practice forestry on certain sites or with certain species and not being able to do this at all.

Selection Involving Progeny Testing Under Field Conditions

Progeny testing in the field serves actually two purposes, the evaluation of the progenies of the selected trees, giving the information necessary for seed orchard roguing, and the establishment of stands of trees from which second-generation selections can be made. Both goals are equally important. In this discussion we are primarily concerned with the improvement obtained through roguing of seed orchards. If the methods outlined by Namkoong et al. (1966), are used and assuming that it will be possible to remove half of the clones out of an orchard by roguing, the progress by roguing will be approximately half of that obtained by the initial selection.

Some Investment Considerations

The chief investment considerations of the seed orchard can be summed up as follows:

1. The cost of setting up a seed orchard contains a fixed portion, determined by the number of clones in the orchard and the progeny-testing scheme adopted, and a variable portion, which is dependent on the size of the orchard.

2. The return to be expected on the orchard will depend on the number of acres that will eventually be planted in improved seedlings raised

from seed obtained from the orchard. This is therefore controlled by the size and the productivity of the orchard. The situation becomes more favorable in the larger orchards, since the fixed cost remains the same while the return increases.

3. The various activities in a seed orchard program do not promise equal investment returns.

4. The smaller the seed orchard the less elaborate the selection procedure one can afford, perhaps only including the most profitable steps in the selection process, until the orchard becomes so small that its operation is no longer profitable.

FUTURE SEED ORCHARDS

I would like to conclude with some comments on the developments one can expect in seed orchards. Taking the development of second-generation seed orchards for granted, the key question to be raised is whether the cycle of selection, seed-orchard establishment, progeny testing, and selection among progenies needs to be repeated indefinitely in this order. The answer is a very definite no. Seed orchard establishment is independent of selection and progeny testing, and the present procedure is to some extent a stopgap measure necessitated by the lack of previous experience and the urgent need for the availability of large quantities of improved seed on rather short notice. There are, however, other alternatives, such as the separation of seed-orchard establishment from breeding per se. This would open up the possibility of setting up orchards from clones which already have been tested, thus doing away with the need for progeny testing. In addition it will be possible to anticipate some of the problems that might occur with particular clones, such as incompatibility or inherently poor flower production, so remedial measures can be applied before the problem becomes serious. One would pay for increased productivity per acre of seed orchard by a delay in time of the availability of particular improved materials. However once the immediate need for seed is less urgent there may be a real opportunity in this type of approach.

SUMMARY

1. Selection for characters affecting quantity is quite straightforward. Many characters, however, affect both quantity and quality or quality alone. In these cases selection objectives may differ widely from organization to organization, since quality has to be defined in terms of the end use.

2. Because of practical considerations some form of multiple-trait selection has to be practiced in forest trees. We no longer have to rely on empirical schemes, but are getting enough information to construct selection indexes based on genetic principles.

3. In devising a selection system for forest trees, the most crucial consideration is the biology of the species. It is not desirable to devise a generalized selection scheme for all species.

4. A tool which has not been used so far in forest tree genetics is mathematical programming. This extremely powerful technique can be adapted to tree improvement problems and its use is strongly advocated.

5. A detailed scrutiny of the likely investment returns from tree improvement reveals that it is difficult to consider the selection for individual properties separately. One must rather look at groups of related activities. Some of the main principles are: a) the cost of setting up a seed orchard contains a fixed portion, determined by the number of clones in the orchard and the progeny-testing scheme adopted, and a variable portion, which is dependent on the size of the orchard. b) The return to be expected on the orchard will depend on the number of acres that will eventually be planted to improved seedlings raised from seed obtained from the orchard. The return is therefore controlled by the size and the productivity of the orchard. The situation becomes more favorable in the larger orchards, since the fixed cost remains the same while the return increases. c) The various activities in a seed-orchard program do not promise equal investment returns. d) The smaller the seed orchard the less elaborate the selection procedure one can afford, perhaps only including the most profitable steps in the selection process, until the orchard becomes so small that its operation is no longer profitable.

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A SELECTION SYSTEM FOR SUPERIOR BLACK WALNUT TREES AND OTHER HARDWOODS

Walter F. Beineke and William J. Lowe [1/]

Abstract. -- Black walnut and several other valuable hardwood species usually grow in mixed unevenaged stands. Unfortunately, the selection of superior trees in mixed, unevenaged stands does not permit the use of comparison trees as in pure evenaged stands.

A point system based on knowledge of variation within a species has been developed and applied to black walnut in Indiana. Trees are not compared to others within the stand but to those throughout the geographic area of selection. Characteristics rated were restricted to the few most important that could be measured objectively and included total height, worth up to 5 points; diameter, 5 points; apical dominance, 10 points; branch angle, 10 points; and crook, 10 points.

Some modifications are suggested for the application of the point system to other species.

Superior tree selection has generally been accepted as the initial phase of any progressive tree improvement program. Several sophisticated systems of determining superior trees have been developed, particularly for coniferous species. Superior tree selection is considered by many to be an "easy" preliminary step in the development of genetically superior forests. However, when one actually gets into the woods, he is suddenly faced with the fact that there are often many trees in each stand that could meet the basic criteria for a superior tree and he is confronted with the difficult task of deciding objectively which trees to accept and which to reject. It has been our experience that often trees are brought to our attention simply because of large size and contains only one short, large diameter log. This situation invariably leads to the landowner asking, "What's wrong with it? The veneer buyers certainly are after it." This selection system answers the question satisfactorily.

In evenaged coniferous forests selection systems have been developed on the basis of comparing the superior tree to its evenaged neighbors. However, in the Central States and increasingly in the South, we are dealing with hardwood species which often occur in unevenaged stands or as scattered specimens of the species in evenaged stands, comparison trees are either non-existent or unsuitable.

[1/] Respectively, Assistant Professor of Forestry and Graduate Research Assistant, Department of Forestry and Conservation, Purdue University, Lafayette, Indiana

Therefore, a selection system has been developed based on a point system adapted to existing knowledge of the variation found in black walnut in Indiana. This point system could easily be modified for other hardwood and coniferous species where comparison trees are not available. One advantage of this system over the comparison tree systems is that isolated individuals can be rated in private lawns, along fence rows, or in open fields that otherwise could not be considered. In black walnut some of the better trees are located in these non-forested areas.

Black walnut differs radically from the southern pines in form, site requirements, abundance, and value per tree.

The form of black walnut is best described as undesirable when compared to pine. It tends to fork low on the bole, have an extremely steep branch angle, and it is nearly impossible to find a truly straight stem. The site requirements of walnut for best development are exacting. It requires a moist, yet well-drained, deep soil with an adequate supply of nutrients (Auten, 1945). Black walnut is certainly not as abundant within its range as are the southern pines within their ranges, and black walnut tends to grow in mixed stands with a multitude of other hardwood species (Brinkman, 1957). Black walnut's value per tree is well documented, but it leads to serious problems in the selection program (Brundage and Straszheim, 1968). Most of these selections are from private land--mostly small farms with 40 acre woodlots. There is great pressure on these people to sell their black walnut--especially selected trees. Many landowners cooperate exceedingly well and have turned down offers as high as $7,000 for one of our selections. Others have, of course, succumbed and selections have been cut and sold before seed or grafting material could be obtained. One of our selections sold for $12,600 but grafting wood was obtained and this tree is preserved. At least three selections have been stolen including the tree having the highest point rating in the state.

In considering characteristics of importance to select for, it has been concluded that apical dominance, branch angle, and straightness are probably of at least equal importance with rapid growth rate. The one defect that is evident in every black walnut plantation that has been observed is a "bushy" growth habit.

Evidence has been observed to suggest that apical dominance is controlled by genetic factors. The best walnut sites are usually areas of poor air drainage. In one plantation located in a severe frost pocket late frosts occur nearly every spring. These frosts result in the death of the expanding terminal bud. After a late frost, the new growth begins with the whorl of buds directly below the dead terminal bud. The usual pattern is for three to five of these buds to grow at an angle of from 20 to 50 degrees with none asserting dominance, and a forked, bushy tree develops. However, within this plantation there are six trees out of 350 that produce a new shoot which asserts dominance, and the stems continue growing straight year after year. Branches form from the whorl but then grow at 80 or 90 degree angles, thus, allowing the leader to grow straight. This sequence has occurred on the same individuals through

five late spring freezes. The plantation is six growing seasons old. It is apparent that these few individuals have a genetic makeup which allows them to grow straight, and that branch angle is probably closely associated with straightness.

Walnut has a tendency, even when apical dominance and branch angle are good, to develop slight crooks or "wiggles." It is almost a spiral growth habit--not unlike that of many loblolly pines.

Total height and diameter are rated to give some idea of the genetic potential to grow tall, large diameter stems.

These are the only traits that are evaluated. You may question the lack of age or growth evaluation. This is very unfortunate, but the high value of individual trees precludes the use of an increment borer. Some indications of growth rates are being obtained from remeasurement of trees over two to five year periods. Other trees are aged from the dates offered by owners on their knowledge of the history of the land. The bark texture, and ridging is also used as a rough indication of relative vigor. Since black walnut is an intolerant species, most large individuals are dominant in the stand and are generally the oldest individuals in the stand. From this assumption, an indication can be obtained that dominant black walnuts in any one stand are likely to be even-aged, thus the larger individual is usually favored. Remeasurement of selections made 2-5 years ago indicate relatively rapid growth rates. Most selections are growing in diameter at the rate of from 0.2 to 0.3 inch per year with good trees averaging from 0.4 to 0.5 inch at DBH. Two selections are growing at rates as high as 0.7 inch per year in diameter.

Another factor omitted is the rating of wood characteristics. The problem again is one of being unable to bore the selections. In addition, there is considerable argument within the veneer industry as to what constitutes desirable wood (Mathers, 1966). Indiana walnut wood apparently has everything the veneer people desire. The color does vary some, but dark wood usually is preferred and heartwood from fast-grown trees is often darker than that from slow-grown trees (Englerth, 1966). Faster growth rate seems to improve veneering, machining, and grain pattern, therefore, increasing growth should not be detrimental to wood quality (Englerth, 1966).

The opinion has been advanced by many that the important trait in veneer log production should be diameter growth and that a large-crowned, short-boled tree can accomplish this better than a "forest type" tree (Wylie, 1966). However, too many plantations have been observed in which it was impossible to grow even an eight or sixteen foot log before forking. Thus, in a tree that is genetically prone to forking, forking will occur at any height--not exclusively the desirable 16 foot height. It has taken many man hours of pruning to attempt to straighten and repair badly forked and crooked trees in our plantations. The few straight growing individuals require little or no care in the form of pruning. Anyone familiar with labor costs today will appreciate this advantage. In addition the drastic

pruning required to straighten stems destroys leaf area which in turn reduces growth rate (Clark and Seidel, 1961), furthermore, it is our goal to strive for more than one log. Since walnut has this genetic potential, attempts should be made to take full advantage of it.

To date 150 trees have been rated. Out of that 150, 57 have been designated "accepted." Most of the 57 are 25 points or above out of the possible 40 points. The tree with the highest rating has 38 points, and 23 trees are 30 points or over. We are attempting to select trees from throughout the state and certain areas have few black walnuts remaining. In such areas we have been forced to accept selections below 25 points. In addition, some trees are particularly outstanding in one characteristic and we have therefore accepted them in spite of other undesirable characteristics.

Figure one shows the standard rating sheet with the point breakdown and a definition of terms.

PURDUE UNIVERSITY
HARDWOOD SUPERIOR TREE
CANDIDATE REPORT

Tree No.	Species		State	County
Township	Range	Section	Forty	
Tree Located By				Date
Tree Graded By				Date
Remarks				
Recommendation			Accepted Date	Rejected Date
Landowner			Address	
Tree Marked With				

Selected Tree Rating — MAP

	Measurements	Pts	Remeasured	Remeasured
Date				
DBH (in.)				
Total ht. (feet)				
Ht. to 1st Fork (ft.)				
Apical Dom. (%)				
Branch (degrees)				
Crooks (no. to fork)				
Seed Crop				
Age (yrs.)				
Growth rate (in per yr.)				
Total Pts.				

Please complete two forms for each candidate. Send one copy to Walter Beineke, Department of Forestry & Conservation, Purdue University, Lafayette, Indiana, and one copy to Richard McNabb, Assistant State Forester, 607 State Office Building, Indianapolis, Indiana.

INSTRUCTIONS

MAP: Draw a simple map indicating roads (numbered or named), landmarks and distance to tree.

MARKING: Preferable marking is with a band of white paint at head height.

DBH: Measure diameter at 4½ feet to nearest 0.1 inch.

TOTAL HEIGHT: Measure total height to nearest foot with clinometer, Abney or Haga.

APICAL DOMINANCE: Measure stem length to the first fork. Record as percentage of total height. One or more of the following conditions constitutes forking: (a) the smaller of two adjacent branches exceeds 1/3 the diameter of the larger or (b) the main stem is deflected more than 10° at the juncture or (c) the angle between the branch and main stem is less than 25°.

BRANCH ANGLE: Measure the angle in degrees between the main stem and branch. Measure on the third live branch from the ground located on the central stem or on the dominant fork.

CROOKS: Count the number of deviations of the central stem from the vertical plane below the first fork.

SEED CROP: Indicate whether heavy, medium, light, or none depending on past experience with the species (Standards for black walnut are: light 1-50 nuts: medium 50-200; heavy over 200).

AGE: Do not bore black walnut. You may be able to obtain permission to bore cottonwood, sycamore, and other less valuable species. If you can find the approximate age of black walnut, tulip, etc please record and indicate how arrived at.

GRAIN PATTERN: Reject all trees having spiral grain.

SWEEP: Reject all trees having visible or excessive sweep in first 16 feet.

LEAN: Reject all trees which appear to be leaning unless it is caused by streambank erosion.

ROUNDNESS: Reject all trees that are obviously not round in cross section.

POINT SYSTEM FOR RATING SUPERIOR BLACK WALNUT TREES

Total Possible Points = 40

Diameter	Height	Apical Dominance	Branch Angle
Over 22" -- 5 pts	Over 120' -- 5 pts	Over 70% -- 10 pts	Over 70° -- 10 pts
18-21.9" -- 4 "	100-119' -- 4 "	65-69% -- 9 "	65-69° -- 9 "
14-17.9" -- 3 "	80- 99' -- 3 "	60-64% -- 8 "	60-64° -- 8 "
10-13.9" -- 2 "	60- 79' -- 2 "	55-59% -- 7 "	55-59° -- 7 "
6- 9.9" -- 1 "	40- 59' -- 1 "	50-54% -- 6 "	50-54° -- 6 "
Below 6.0" -- 0 "	Below 40' -- 0 "	45-49% -- 5 "	45-49° -- 5 "
		40-44% -- 4 "	40-44° -- 4 "
		35-39% -- 3 "	35-39° -- 3 "
		30-34% -- 2 "	30-34° -- 2 "
		25-29% -- 1 "	25-29° -- 1 "
		Below 25% -- 0 "	Below 25° -- 0 "

Crooks		
Number	Over 16" DBH	Under 16" DBH
0	10 pts	10 pts
1	8 "	9 "
2	6 "	8 "
3	4 "	7 "
4	2 "	6 "
5 +	0 "	5 "

Figure 1. -- Purdue University hardwood superior tree candidate report.

At first glance the point system appears to be very arbitrary. However, it has been designed so that the values bracket the usual range of a given characteristic that has been found in black walnut. For instance, apical dominance of over 50% in black walnut is unusual and over 70% practically non-existant. Out of the 57 trees accepted only two are over 70%, and the average is 52%. In this selection system apical dominance is measured to a fork as defined on the rating sheet, Figure 1.

Branch angle is more difficult to determine than apical dominance. Choosing the branch to be measured for branch angle is not as objective as we would prefer. The third live branch from the ground is often difficult to determine, but once selected, it seems to give a good estimate of the branch angle found in the crown of the tree. One difficulty is encountered with open grown trees where branches are found on the lower bole. These branches often have flatter branch angles than those in the crown, but this is usually compensated for by poor apical dominance. The average branch angle for the 57 selections is 54 degrees and 10 of the 57 are over 70 degrees. Six of the 10 are exactly 70° and only one has a 90° branch angle.

The point system for crooks was divided into two classes based on size. The theory is that a smaller tree has much greater chance of having visible crooks that a very large tree has outgrown. Twenty of the 57 selections have no crooks and only five have as many as three crooks, and three of these are under 16" DBH. Several individuals with four crooks have been rejected, no trees with five crooks have been seriously rated to date. They do quite commonly exist but are rejected without rating because their form is too poor for further consideration. Counting crooks is probably the most subjective trait in the rating system and often compromises must be made.

The diameter of the selections ranges from 7" to 45" and averages 21". Their height ranges from 30' to 148' and averages 96'. Some indication of seed crop is asked for on the selection sheet, and frequency and size of seed crops is recorded. Trees that have noticeable or excessive sweep, lean, spiral grain, and poor roundness are rejected without further consideration.

Application of the rating system to other species will require modifications depending on the characteristics of the species. Comparison trees are often available in tulip poplar. In spite of that fact, it will be used for purposes of illustration. In tulp poplar the points for apical domimance and branch angle would necessarily be distributed higher than they are in black walnut. Tulip poplar is also straighter than walnut, thus, fewer crooks would be allowed. Growth rate might be included, since it is possible to obtain increment cores from tulip poplar. Although we haven't worked much with tulip poplar, the point system might appear as follows:

Apical Dominance

90-100%	--	10 pts
85- 89	--	9 "
80- 84	--	8 "
75- 79	--	7 "
70- 74	--	6 "
65- 69	--	5 "
60- 64	--	4 "
55- 59	--	3 "
50- 54	--	2 "
45- 49	--	1 "
40- 44	--	0 "

Branch Angle

90-100°	--	10 pts
80- 89	--	9 "
75- 79	--	8 "
70- 74	--	7 "
65- 69	--	6 "
60- 64	--	5 "
55- 59	--	4 "
50- 54	--	3 "
45- 49	--	2 "
40- 44	--	1 "
35- 39	--	0 "

Crooks

Number	Over 16"	Under 16"
0	10 pts	10 pts
1	6 "	7 "
2	4 "	6 "
3	2 "	5 "
4	0 "	4 "

Success in the genetic improvement of our valuable hardwood species must be predicated on the thorough and careful selection of superior individuals to be utilized as raw genetic material in seed orchards and breeding programs. Selection systems, such as this one devised for black walnut, will enhance the probability that valuable genetic material will not be irretrievably lost for lack of an objective comparative method of superior tree selection.

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NATURAL VARIATION IN SEED CHARACTERISTICS AND SEED YIELD OF BLACK WALNUT IN THE TENNESSEE VALLEY

T. G. Zarger, R. E. Farmer, Jr., and K. A. Taft, Jr.[1/]

Estimates of seed orchard yields are needed early in breeding programs so that orchard areas adequate to meet expected demands for seed may be established. This is especially true for large-seeded hardwoods that begin bearing large crops late in life. Thus data on seed yield and seed characteristics of black walnut (Juglans nigra L.) are needed in current breeding efforts.

In the 1940's, the Tennessee Valley Authority conducted a project to develop black walnut trees having high quality seed in terms of kernel production. Seed yield data from typical open-grown trees throughout the Tennessee Valley were collected annually from 1940 through 1947. Six-year data, with emphasis on kernel characteristics, were published by Zarger (1946). Additional data are presented here with emphasis on their use in breeding programs aimed at improving timber quality.

METHODS

Seed yield and quality data for eight consecutive years from 115 open-grown trees were analyzed. These trees were located from western North Carolina and Virginia to west Tennessee; eastern and western portions of the Tennessee Valley were equally represented in the sample. DBH of the trees ranged from 6 to 26 inches at the end of the sample period, at which time they were from 14 to 71 years old.

Each year all fruit was collected from each bearing tree and weighed in the field. When yield per tree was less than 100 pounds of unhusked seed, the entire crop was husked and the cleaned seed was weighed after air-drying for one month. Larger crops were sampled to obtain estimates of total yield of air dried seed. Individual seed weight, percent filled seed, and kernel weight were estimated from a random sample of 20 seed per crop per tree.

In addition to DBH, which was recorded annually for all trees, crown radius, age, and height were measured on 94 trees in 1947.

A linear multiple regression analysis of mean annual seed yield on 1947 DBH, age, height, and crown radius showed that yield was positively related to tree size. An analysis of covariance with DBH as the independent variable

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1/ The authors are respectively Research Forester, Plant Physiologist, and Geneticist, Forest Tree Improvement Section, Division of Forestry Development, Tennessee Valley Authority, Norris, Tennessee. They wish to thank D. T. Funk and E. Thor for helpful reviews of the manuscript.

was therefore computed to evaluate tree-to-tree variation in yield. The dependent variable was mean yield of individual trees for two four-year periods, 1940-43 and 1944-47. Use of four-year averages as units of analysis was necessary to reduce variance related to alternate bearing. A hierarchical sampling design with two physiographic regions (eastern and western portions of the Tennessee Valley), five areas per region, and six trees randomly selected per area was used to evaluate geographical effects.

Tree-to-tree variation in seed characteristics was evaluated using data from four randomly-selected crops per tree. For filled seed weight and percent filled seed (arcsin transformations), an analysis of covariance was computed with yield as the independent variable. Simple analyses of variance were computed for kernel weight and arcsin transformations of kernel weight as a percent of filled seed weight. Simple correlation coefficients were calculated for relationships among several tree and seed characteristics.

RESULTS

Tree-to-tree variation in mean annual seed production is illustrated in Figure 1 for two DBH classes: 10-15 inches (55 trees) and 15+ inches (37 trees). Twenty-three trees under 10 inches DBH each produced (with one exception) less than 20 pounds (about 500 seed) per year.

While mean annual seed yield data give an accurate picture of long-term production, they give poor estimates for a tree in any given year because of walnut's inconsistent bearing pattern. Forty percent of the trees exhibited distinct alternate year bearing and seven percent consistently produced seed two out of three or one out of three years. The remaining 53 percent of the trees had no pattern. Alternate bearing trees were found in all geographical areas.

The multiple regression of average seed yield (pounds per tree) over tree-size parameters produced the following equation: yield = -50.685 + 4.763298 crown radius + 0.656074 DBH + 0.032171 height - 0.387097 age. Forty-two percent of the variation in yield was accounted for by the four independent variables; crown radius and DBH were most important in accounting for variation in seed yield. Coefficients for simple correlations between yield and tree size parameters are given below:

	Yield
DBH	.52
Age	.17
Crown Radius	.63
Height	.37

Table 1

Analyses of Variance in Black Walnut Seed Yield and Seed Characteristics

Source of Variation	Crop Weight df	Crop Weight Percent of Total Variance	Percent Filled Seed df	Percent Filled Seed Percent of Total Variance	Filled Seed Weight df	Filled Seed Weight Percent of Total Variance
Trees	114	59	92	50	92	60
Samples/Trees	114	41	278	50	278	40

	Kernel Weight df	Kernel Weight Percent of Total Variance	Percent Kernel Weight df	Percent Kernel Weight Percent of Total Variance
Trees	36	76	36	69
Samples/Trees	111	24	111	31

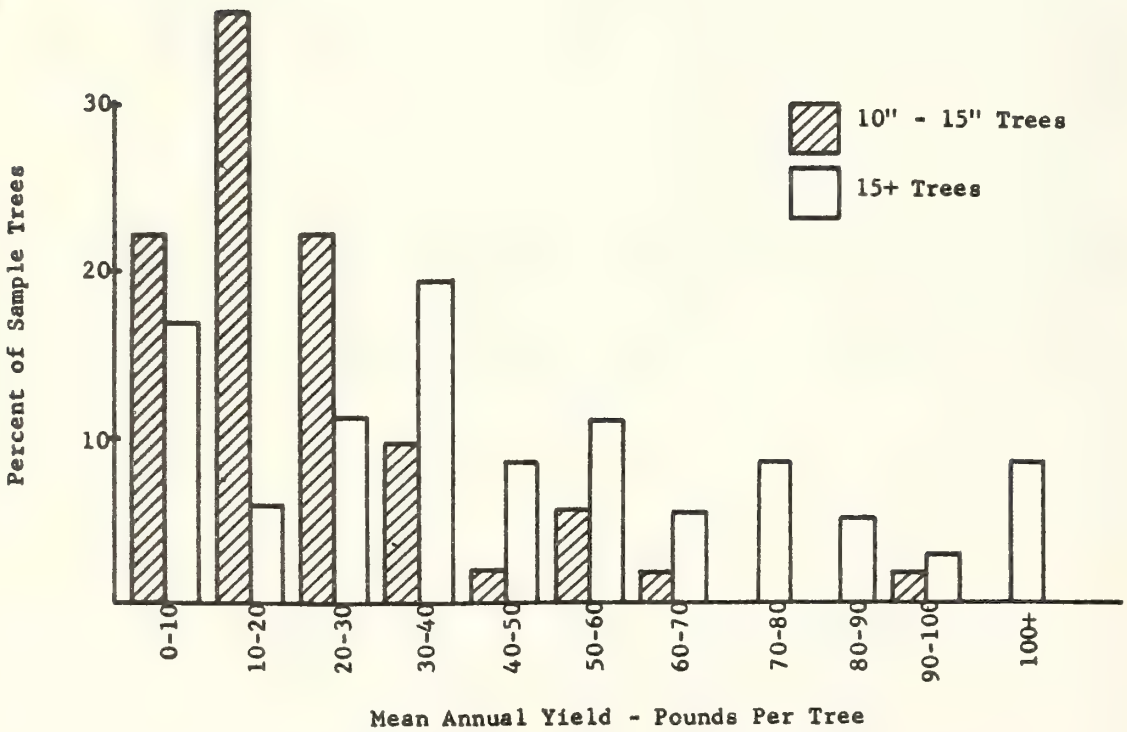


Figure 1. Natural variation in yield of air-dried black walnut seed in the Tennessee Valley.

Evaluation of yield variation by physiographic regions, areas within regions, and trees within areas indicated that regions and areas were not significant sources of variance. After adjustment for tree size, differences among trees within areas accounted for 65 percent of the yield variance. Since tree-to-tree differences were the only significant source of variance in the hierarchical analysis, a covariance analysis was used to evaluate individual tree variation in the entire sample (Table 1). In this analysis, 59 percent of the crop weight variance was associated with trees.

Filled-seed percent for individual trees varied from seven to 100 (Figure 2) and was not strongly correlated with yield (r= .17). The distribution was skewed to the right with 31 percent of the trees having over 90 percent filled seed. Fifty percent of the variance was associated with individual tree differences (Table 1).

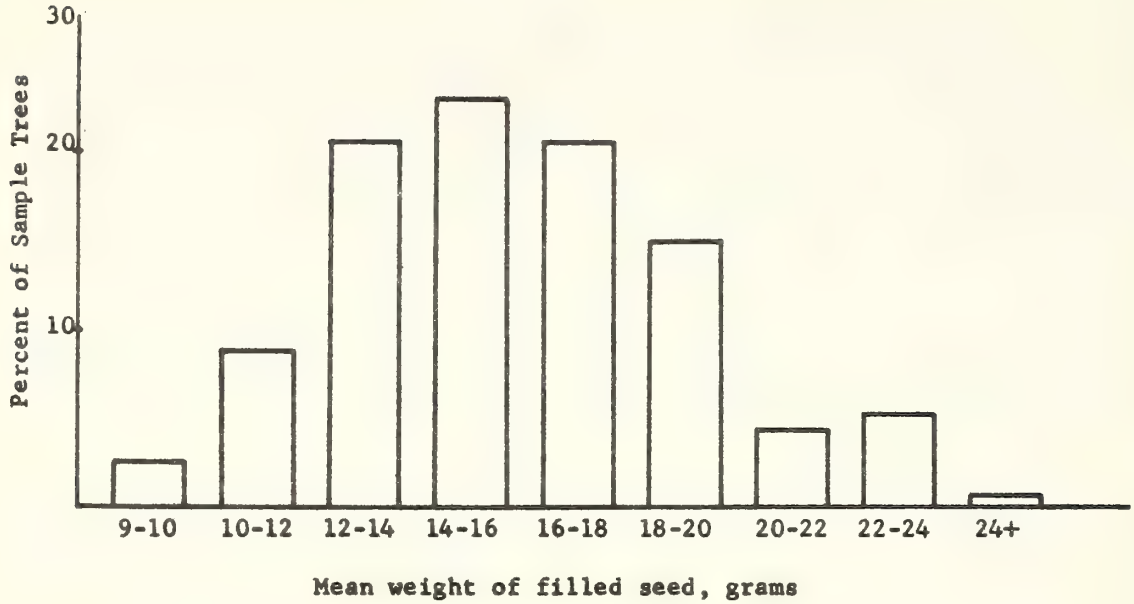
Average weight of filled seed (Figure 2) was distributed normally from 9.0 to 24.2 grams with a mean of 16.5 grams. The correlation of crop weight with seed weight had a coefficient of .17, and 60 percent of the variation in seed weight was due to differences among trees.

Mean kernel weight of individual trees (Figure 3), which ranged from 1.7 to 6.4 grams, was strongly correlated with filled seed weight (r = .84) and moderately with kernel weight expressed as a percent of seed weight (r = .62). Distribution of kernel weight was skewed slightly to the left but the distribution of kernel weight as percent of seed weight was approximately normal. Individual tree differences accounted for 76 percent of the variation in kernel weight and 69 percent of the variation in kernel percent (Table 1).

CONCLUSIONS

This study indicates that seed yields and seed characteristics of individual black walnut trees vary widely in the Tennessee Valley and that much of this variation is attributable to individual tree differences unrelated to tree size or geographic location. This variation pattern, which is also evident in oaks (Downs and McQuilkin, 1944; Christisen, 1955; Ried and Goodrum, 1957), suggests that seed yield may be under fairly strong genetic control and thus subject to effective field selection.

Some direct evidence for effective field selection for seed size was found by Zarger (1945) who tested (as grafted clones) 90 trees located throughout the walnut range and selected for high kernel weight and/or percent. Means for this group of 90 clones shown in relation to random sample means of the present study are as follows:



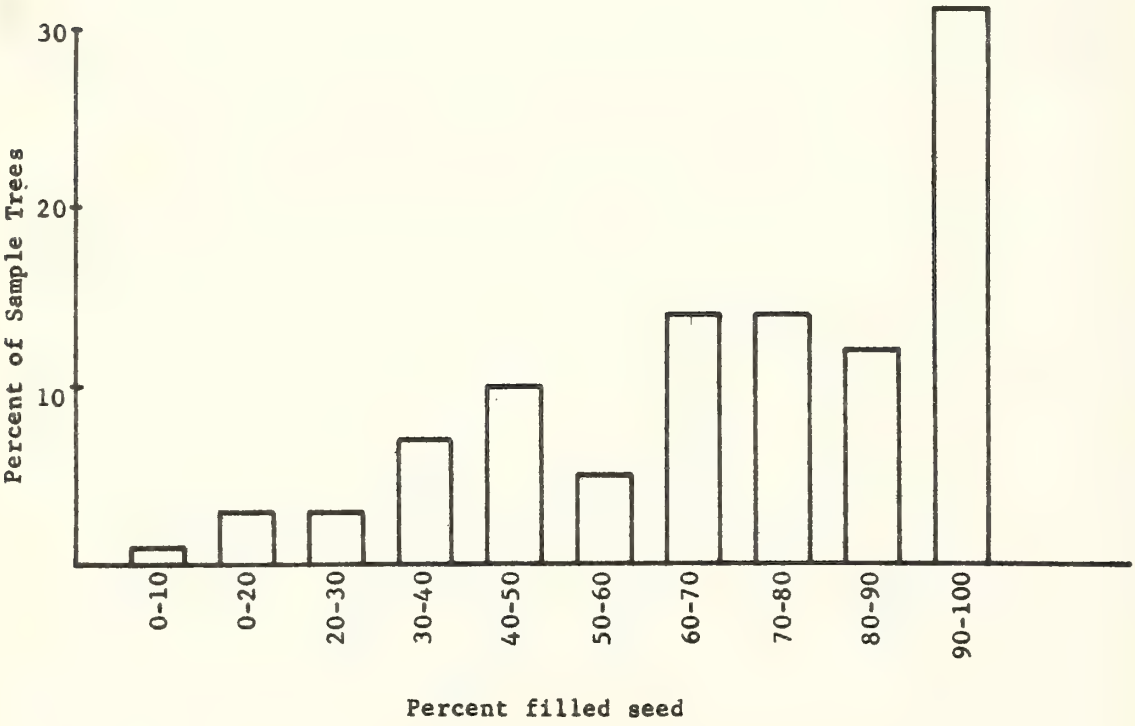
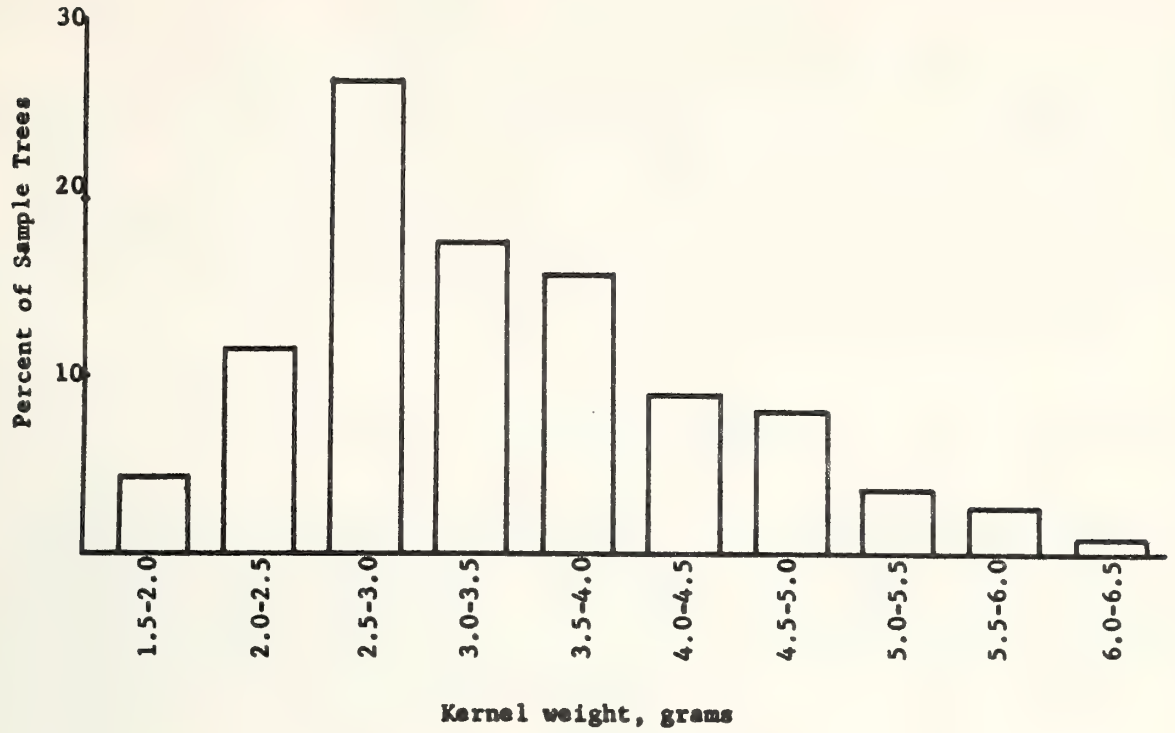


Figure 2.--Natural variation in seed weight and percent filled seed of black walnut in the Tennessee Valley.



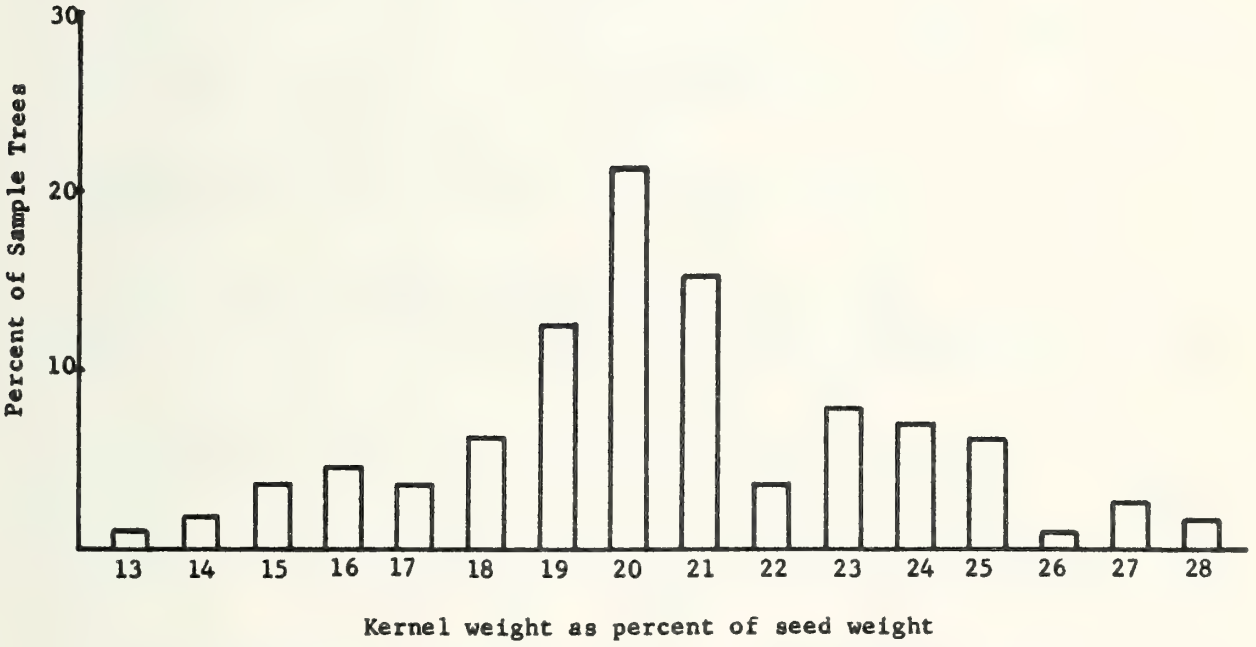


Figure 3.--Natural variation in kernel weight and percent kernel of black walnut seed in the Tennessee Valley.

	Random Sample	Ninety Selected Clones	Selection Differential, Percent
Weight of filled seed, g	16.5	19.6	19
Kernel weight, g	3.3	5.1	55
Kernel percent	20.0	27.0	35

Chase (1947) found that large black walnut seed, especially those with large kernels, produce larger seedlings than small seed; and Williams (1965) noted that large seedlings survive and grow better than small ones. Thus selection for seed size should result in gains for survival and juvenile growth.

Since seed yield varies considerably among trees, seed production should be considered when selecting phenotypically superior trees for orchards. Little benefit will accrue from initial selection for growth and form if the selections are inherently poor seed producers. Conversely, trees with extremely high fecundity may produce progeny which bear large seed crops at the expense of wood production. An awareness of the inconsistent yearly bearing patterns of individual trees is also essential in both field selection and orchard management. Even ramets of the same clone within an orchard show variation in this bearing pattern (Taft, 1966).

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PRELIMINARY SELECTION OF EASTERN COTTONWOOD CLONES

C. A. Mohn and W. K. Randall[1/]

The Southern Forest Experiment Station is identifying fast-growing clones of eastern cottonwood (Populus deltoides Bartr.) both to meet growing demands for genetically improved planting stock and to obtain a base population for future breeding experiments. We have completed a series of preliminary seedling and clonal tests and have gathered early data from some long-term clonal tests. This paper reports responses to extensive preliminary screening and outlines preliminary screening techniques we plan to use in the future.

MATERIALS AND METHODS

The tests began with selection of phenotypically superior female trees in natural stands and ended with long-term clonal tests (fig. 1). Five steps were taken:

1. Field selection (1961-1962). In stands with a large cottonwood component, candidate trees were located through reconnaissance. Growth and form of candidate trees were compared with those of the five closest dominants or codominants. Selection was confined to 20- to 30-year-old trees on the Mississippi flood plain between Clarksdale and Vicksburg, Mississippi. Twenty-five females were selected for parents of the study population. The intensity of selection in this step is unknown.

2. Open-pollinated progeny test (1962-1963). A seedling population of open-pollinated progeny from the 25 selected trees was tested on a silt-loam soil. Details of the procedure were reported by Farmer and Wilcox (1966). Spacing was 2 by 3 feet. Approximately 4,000 seedlings (about 160 per family) were evaluated. Selection was made in two substeps:

   2a. A population of 93 seedlings was selected after the first year of testing. These genotypes were tested again in step 3.

   2b. The seedlings studied were cut at groundline at the end of the first growing season. The next year the clumps of sprouts were thinned to a single stem per seedling. The 31 clones which made up population "b" were selected after 1 year of sprout growth and used in step 4.

3. Clonal test I (1963). The 93 seedlings selected in step 2a were cloned and planted on a silt-loam soil. Spacing was 5 by 5 feet. There were three replications, each containing a single ramet of each clone. An evaluation of first-year development led to retention of 67 clones which were tested in step 4.

1/ The authors are stationed at the Southern Hardwoods Laboratory, which is maintained at Stoneville, Mississippi, by the Southern Forest Experiment Station, USDA Forest Service, in cooperation with the Mississippi Agricultural Experiment Station and the Southern Hardwood Forest Research Group.

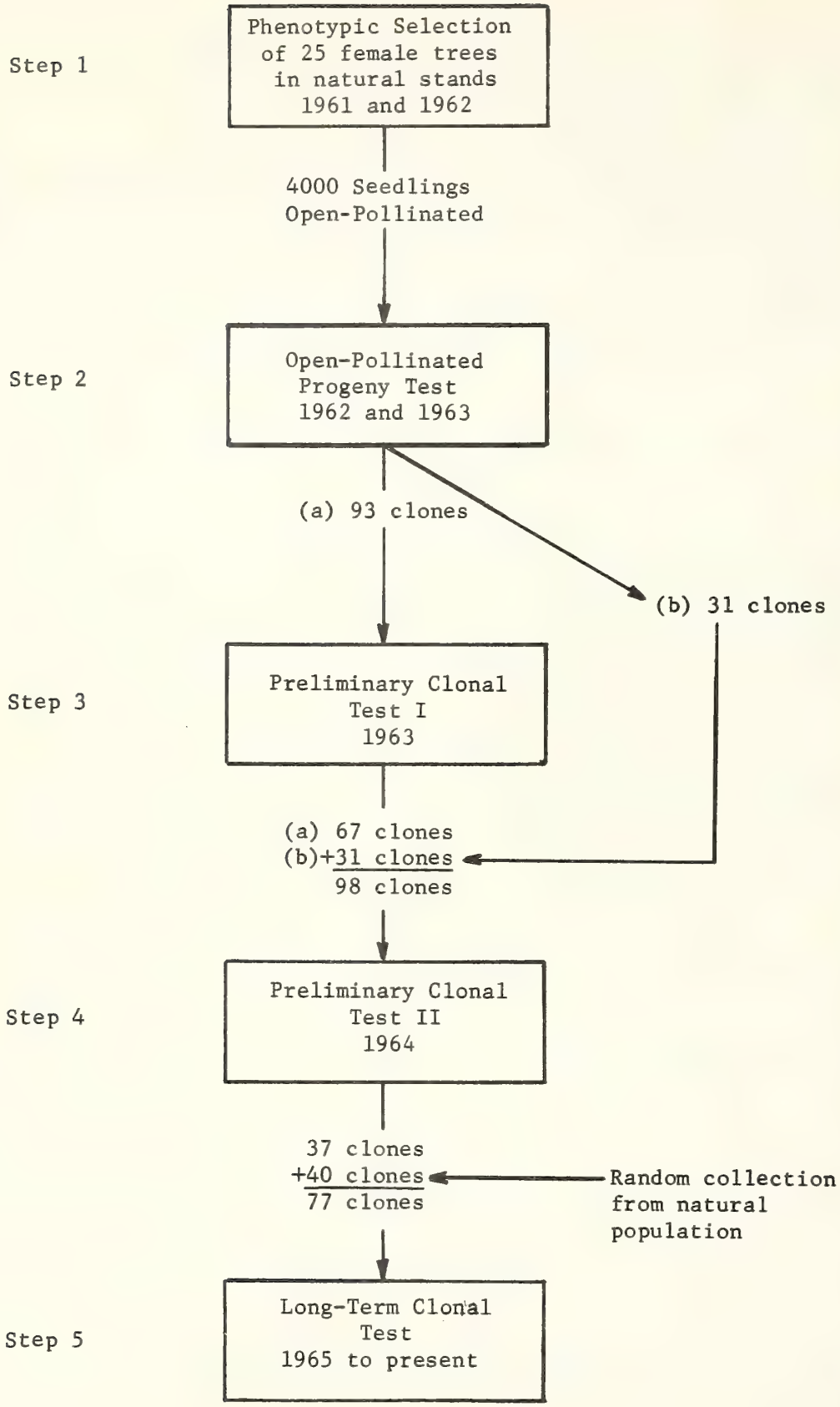

Figure 1.--Steps in the development of a population of clones now in a long-term clonal test.

4. Clonal test II (1964). The 67 clones obtained from step 3 plus the 31 from step 2b were evaluated. A triple lattice design provided for nine ramets per clone--three replications and three ramets per plot. Two clones commonly used in commercial plantings were used to raise the number of clones to 100. Spacing was 6 by 6 feet and the test was installed on two soil types: a silt loam and a heavy clay. Measurements made after one growing season were reported by Farmer and Wilcox (1968). The 37 clones selected at the end of the first year were entered in long-term tests.

5. Long-term clonal test (1965 to present). Performance of the 37 clones that survived preliminary selection is being compared with that of 40 cloned seedlings collected at random in the same area as step 1. A randomized complete block design was used with five replications on a heavy clay soil and five on a silt-loam soil. Plots contained four ramets. Spacing was the same as that commonly used in commercial plantings, 10 by 10 feet. Plots on the "good" site (silt-loam soil) were thinned after the third year, reducing stocking to two ramets per plot. Third-year height and fourth-year diameter data are reported here.

Selection

Selection was carried out at several stages, under a variety of conditions. In steps 1 and 2, individual trees were selected on the basis of their phenotypic values in the natural population or in an even-aged seedling population grown at a uniform spacing. In steps 3 and 4, clones were selected on the basis of the mean performance of several ramets. In the evaluation of phenotypes, several traits were considered and no rigidly defined criterion was common to all steps.

The complexities described and the relatively small amount of data available preclude an accurate quantitative description of the total selection process. Descriptions of selection were quantified individually for steps 2, 3, and 4. The treatment of data was related to the type of selection. In step 2, individual plant measurements and their variances were considered; in steps 3 and 4, clone means were the basic unit of analysis. Populations "a" and "b" in step 2 were treated separately. For convenient comparison, population "b" was described on the basis of first-year (seedling) data. Description was simplified by dealing with the two traits, height and diameter, independently. Descriptions include:

1. The proportion of the population selected.

2. The standardized selection differential (deviation of the select population from the test population mean in units of phenotypic standard deviation).

This value was computed directly from the data collected in each experiment.

3. The equivalent proportion of the population selected. Simultaneous selection for several traits upset the relationship between the proportion of the population retained and the standardized selection differentials (Falconer 1960, pp. 193-194). The proportion of the population retained, therefore, is

not particularly descriptive of selection for a trait. The standardized selection differentials were used to approximate the proportion of the study population which could have been retained to produce a select population with the observed means. Proportions equivalent to the selection differentials were obtained from tables for populations of given sizes (Becker 1967). Use of these tables required an assumption of normal distribution. The distributions of phenotypic values in the two clonal tests (steps 3 and 4) were approximately normal when graphed.

Values were computed to relate the select population at the end of each step to the mean of the seedling population. The products of the equivalent proportions selected in the successive steps were used to provide an estimate of the proportion of the seedling genotypes retained. Thus, if the equivalent of 10 percent of the population was retained in the first step, the retention of 50 percent of the test population in the second step would result in a "maximum equivalent proportion of genotypes" of 5 percent. This approach was used in all cases, except when populations were combined and appropriate maximum standardized selection differentials were obtained from standard tables. In combining populations, weighted averages of the maximum standardized selection differentials for the populations being combined were computed and used to obtain the equivalent percents. These calculations were made under the invalid assumption that the performance of materials in all steps was perfectly correlated. The selection intensities therefore were inflated, and they are termed "maximum" in the tables.

RESULTS AND DISCUSSION

The select population in the long-term tests performed considerably better than the random population. Height gain in standardized units was 0.993 on silt loam and 0.673 on clay (table 1). Diameter gain was 0.826 on silt loam and 0.465 on clay. These gains demonstrate that preliminary selection is advantageous.

Table 1.--Response in long-term test to preliminary selection for height and diameter growth

Population mean	Site			
	Silt loam		Clay	
	Third-year height	Fourth-year diameter	Third-year height	Fourth-year diameter
	Feet	Inches	Feet	Inches
Select	38.89	5.96	19.24	2.95
Random	36.97	5.49	18.05	2.76
Gain[1/]	.993	.826	.673	.465

1/ In standardized units: $\frac{\text{select} - \text{random}}{\sigma_{\text{random}}}$

No direct measure can be made of the effectiveness of selection in the individual steps. The expected response (R) to preliminary selection can be described as $R = ri\sigma_p$, where r is the correlation coefficient for performance of clones in the preliminary and the long-term tests, σ_p is the phenotypic standard deviation, and i is the standardized selection differential. Some insight into the relative effectiveness and efficiency of each step is provided by examination of r and i.

Table 2 gives selection intensities for each step and maximum standardized selection differentials for steps 2 through 4. The differences between the actual and the equivalent proportion retained indicate the loss in potential selection intensity caused by the selection procedure. Contributing to this loss were consideration of several traits rather than one and the retention, for experimental purposes, of materials which would normally have been discarded. Selection was most intensive in step 2a because of the large number of genotypes screened and the high weight given to growth traits.

Table 2.--Quantification of selection in steps 2 to 4

Step	Step values					Cumulative values		
	Test mean[1/]	Number of plants retained	Proportion of population selected	Standardized selection differential	Equivalent proportion of population selected	Proportion of genotypes retained	Maximum equivalent proportion of genotypes	Maximum standardized selection differential
				Height				
2a (progeny test)	3.83	93	0.023	1.973	0.062	0.023	0.062	1.973
3 (clonal test I)	13.67	67	.720	.331	.810	.017	.050	2.063
2b (progeny test)	3.83	31	.007	.110	.949	.007	.949	.110
2b + 3	...	98	...	...	...	.024	.184	1.445
4 (clonal test II)								
(silt loam)	12.61	37	.375	.608	.620	.009	.114	1.692
(clay)	11.49	37	.375	.586	.637	.009	.117	1.679
				Diameter				
2a (progeny test)	13.6	93	.023	1.342	.222	.023	.222	1.342
3 (clonal test I)	1.50	67	.720	.357	.789	.017	.175	1.473
2b (progeny test)	13.6	31	.007	.459	.726	.007	.726	.459
2b + 3	...	98	...	...	...	.024	.304	1.152
4 (clonal test II)								
(silt loam)	1.71	37	.375	.426	.749	.009	.228	1.325
(clay)	1.61	37	.375	.334	.810	.009	.244	1.286

[1/] All means for heights are given in feet; mean diameter in step 2 is in millimeters; all others in inches.

The correlation coefficients (r) presented in table 3 provide a rough index of the efficiency of selection in each step. These coefficients must be viewed with reservation because of the large errors associated with their calculation.

Data in table 3 suggest that preliminary clonal tests are valuable. The use of even a small number of ramets in these tests substantially increased the correlation with the long-term performance on the silt-loam soil. If the increase was as substantial as indicated, the gain would more than offset the loss in selection intensity associated with the reduction of genotypes in tests with an equal number of plants.

On the clay soil, there was no clear indication that cloning would increase the effectiveness of preliminary evaluation. The data may have reflected a confounding influence of soil type, since the progeny test and first clonal test (steps 2 and 3) were carried out only on a silt-loam soil. In step 4, correlations were apparently increased by running the tests on similar soils. Preliminary tests should probably be made on soils similar to those on which the material will be utilized.

Low or even negative correlations were found between growth of sprouts from clipped seedlings and growth of the same genotypes in long-term clonal tests. Apparently, it is not advisable to evaluate on the basis of sprout performance.

No apparent changes in the correlation coefficients were associated with the increase in plot size from one to three ramets in step 4. On the basis of these data, it is recommended that plot size be kept small (one or two ramets) in preliminary clonal tests.

Phenotypic selection in natural stands may also have contributed to the observed gain. Farmer (in press) found that field selection of parents, using the system employed in step 1, was "completely ineffective" in terms of 1- and 2-year growth of progeny. There is, however, evidence that field selection contributed to the superiority of third-year height and fourth-year diameter growth of the select population.

The standardized gain in the long-term test (table 2) was divided by the maximum standardized selection differential reached after step 4. The quotient provides an estimate of the minimum average correlation coefficient between the preliminary and final tests required to obtain the observed response. The values calculated were:

	Diameter	Height
Silt loam	0.61	0.59
Clay	.36	.41

Particularly for the silt-loam soil, they are well above any reasonable estimate of the actual mean correlation coefficients based on the values in table 3. Under these conditions it is difficult to rationalize the gain observed on the basis of selection in steps 2 to 4 alone. It seems reasonable to conclude that

the select clones were derived from a seedling population whose mean was higher than the random population as a result of the selection of parents.

Table 3.--Correlation coefficients between values for clones in preliminary tests and comparable values in long-term tests

Steps in the program	Long-term test			
	Silt loam		Clay	
	Fourth-year diameter	Third-year height	Fourth-year diameter	Third-year height
Open-pollinated progeny test (step 2)				
2a seedlings--1962	0.1211	0.0806	0.2280	0.3551*
2b sprouts----1963	-.1626	.0206	-.1348	-.0452
Clonal test I (step 3)	.4563*	.5160*	.2815	.3481
Clonal test II (step 4)				
Silt loam	.3415*	.4431*	.2514	.0590
Clay	.1905	.1781	.4142*	.2614

* Significant at 0.05 level with 36 degrees of freedom for steps 2 and 4 and 30 degrees of freedom for step 3.

CONCLUSIONS

Data from the present tests and from earlier results reported by Farmer (in press) are conflicting with respect to the value of phenotypic selection for growth in natural stands. Experiments now in progress will show conclusively the gains, if any, to be expected from such screening.

Based on the results of the present tests, we plan in the future to do very little selection among seedlings. Rather, we plan to do extensive clonal selection. Large numbers of clones will be included to maintain a high selection differential. Each clone will be replicated several times to avoid excessive losses of promising material. Experiments will be designed with two-tree plots, and all will be on excellent cottonwood sites. After one or two growing seasons, less than 10 percent of the clones will be selected for long-term tests on a variety of sites.

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INTRASPECIFIC VARIATION IN GROWTH AND WOOD CHARACTERISTICS OF TWO SLASH PINE VARIETIES GROWN IN SOUTH FLORIDA

Joseph R. Saucier and Keith W. Dorman[1/]

Nearly two million acres of south Florida is cut-over pine land. Some of it has been converted to range land, but much of it is still unproductive. These forest lands are capable of producing valuable forest products, but to do so will require large-scale reforestation. A question often asked by landowners of this region is which variety of slash pine is bested suited for planting, the native South Florida slash pine, Pinus elliottii var. densa, or the typical slash pine, Pinus elliottii var. elliottii.

Each variety has distinct advantages and disadvantages as a commercial forest species. Variety densa is more fire resistant, less susceptible to tip moth attack, and reportedly has greater wood density. On the other hand, planted stock of variety elliottii has greater survival, initiates early growth more rapidly, and is less susceptible to brown spot needle blight.

Growth and other data for our comparison of the two slash pine varieties were obtained from plantations near Fort Myers, Florida. Descriptions of the stands and a comparison of average growth and wood characteristics were published in TAPPI from a paper presented at the third Forest Biology Conference in 1965 (White and Saucier, 1966).

Briefly, our results are based on wood disks cut from 40 trees, 11 years old, of each variety that were planted in a randomized block field test design. At the time of our study, variety elliottii had a superiority over densa of 9 percent in d.b.h., 27 percent in height, and 37 percent in cubic foot volume. Variety elliottii also had 10 percent higher extracted wood specific gravity, 47 percent greater dry weight per tree, 33 percent more latewood, and 52 percent higher field survival. However, variety elliottii had a low percent of wood extractives (2.9 percent) compared with variety densa (4.1 percent).

In this paper we will discuss tree-to-tree differences in variety densa because the data, although limited, are the first available. Brief mention will be made of similarities to, or contrasts with, typical slash pine, which has been more thoroughly studied. In general, our data show that fairly large differences occur among trees in rate of growth, wood specific gravity, tree dry weight, and percentage of latewood. The patterns of variation seem similar to those for other southern pines.

Studies of intraspecific variation help to establish the range in traits within which phenotypic selection of plus trees is possible. Computation of correlations between traits helps guide the tree breeder in selecting for good combinations of good traits. Mating trees with special traits has given striking

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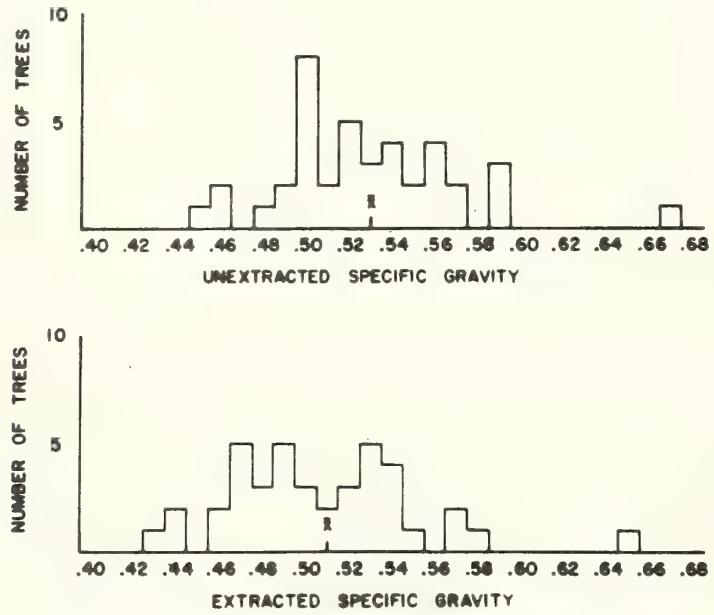
[1/]The authors are Wood Scientist, Forestry Sciences Laboratory, Athens, Georgia, and Principal Silviculturist, Asheville, North Carolina, U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station.

genetic gains in oleoresin yield, tree form, wood quality, volume growth, resistance to fusiform rust, and other less important traits. Thus, results reported here may be of considerable importance in south Florida, although they are not definitive, but they seldom are from such studies because of the large number of variables involved. It is not our purpose to set up requirements for selecting plus trees, but merely to point out some of the possibilities.

RESULTS

Variation in Specific Gravity

Without regard to other factors, the frequency distribution curves for extracted specific gravity seemed to be about normal (Figure 1).


NUMBER OF TREES
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.40 .42 .44 .46 .48 .50 .52 .54 .56 .58 .60 .62 .64 .66 .68
UNEXTRACTED SPECIFIC GRAVITY
NUMBER OF TREES
10
5
.40 .42 .44 .46 .48 .50 .52 .54 .56 .58 .60 .62 .64 .66 .68
EXTRACTED SPECIFIC GRAVITY

Figure 1.--In South Florida slash pine the frequency distribution curve of wood specific gravity shows that phenotypes with relatively high density could be selected. The extracted specific gravity value is also lower than the unextracted value, but the effect of extraction is uniform throughout the range of density among trees. Thus, extraction of wood of high density trees did not lower their values disproportionately.

With a sample of only 40 trees it can be expected that the curve would not be very smooth and the data for the tail ends would be rough. Specific gravity for individual trees ranged from 0.43 to 0.65. The average was 0.51, so the maximum value of 0.65 was 27 percent greater than average. The maximum value was about 50 percent greater than the minimum.

Extraction of wood samples lowered average wood specific gravity 0.02 points. The shape of the frequency distribution curve remained essentially unchanged. Extraction seemed to lower the specific gravity uniformly throughout the range among trees, but there was a slight tendency for it to have more effect on trees with low values than on those with high values. However, the correlation between extractive content and specific gravity was not significant (r = -0.235). The same general relationships held true for typical slash pine.

The low extractive content of trees of high specific gravity would have an important bearing on the amount of genetic gain possible in a selection program for this trait. The wood specific gravity values are high for trees of this age.

Diameter at Breast Height

Tree diameter at breast height ranged from slightly over 2 inches to 5 inches and averaged 3.3 inches (Figure 2).

Figure 2.--Inasmuch as wood specific gravity is positively correlated with d.b.h., selection of fast-growing phenotypes is possible without loss in wood density, but trees of the same d.b.h. may vary as much as 0.10 in extracted specific gravity.

Extracted specific gravity increased with diameter. The correlation coefficient was rather low (r = 0.351), but it was statistically significant. The range in specific gravity for trees of the same diameter was

approximately 0.10 and was relatively constant throughout the range of tree sizes. The two trees of maximum diameter had specific gravity of about average for the group or slightly higher. Tree diameters in typical slash pine varied the same amount among trees, but the correlation of specific gravity with diameter was negative (r = -0.222), although very low and nonsignificant.

Tree Height

Height of individual trees ranged from 11 feet to 24 feet and averaged 17.1 feet (Figure 3).

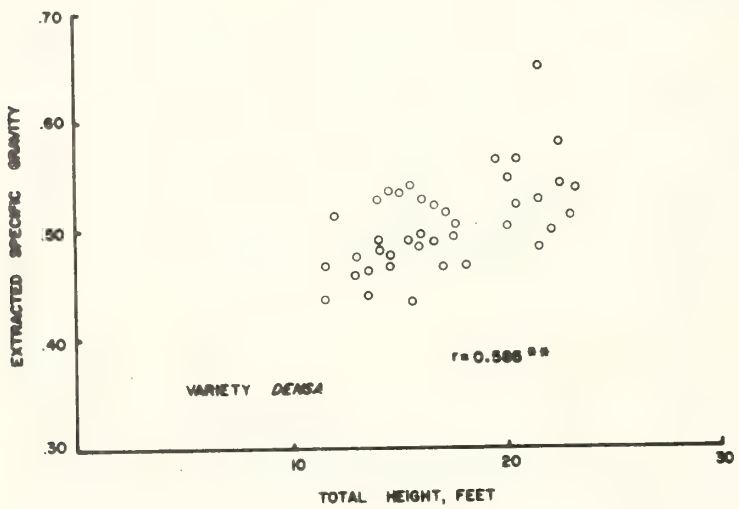

Figure 3.--Selection of phenotypes outstanding in height would result in trees of above average specific gravity, although certain individual trees might be about average because of the variation in wood density among trees of the same height.

Extracted specific gravity increased with tree height, and the correlation coefficient of r = 0.585 was highly significant. The range in specific gravity among trees of the same height was about the same as for diameter, and was uniform throughout the range of tree sizes. One tree near the maximum in height had the highest specific gravity of all trees, 0.66, but was only average in diameter at breast height. In typical slash pine, the height varied the same amount as in variety densa, but the correlation of specific gravity with height was negative and nonsignificant (r = -0.043).

Tree Volume

Total wood volume per tree reflects both diameter and height growth, and had a wide range in this study (Figures 4 and 5).

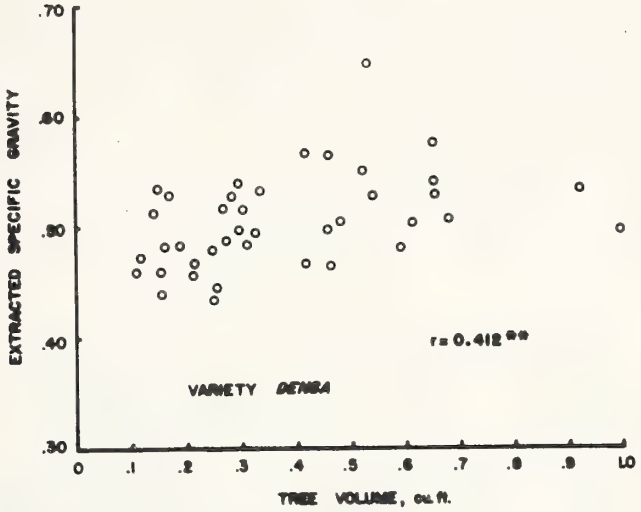

Figure 4.--Selection of fast-growing phenotypes in variety densa would yield trees of average or above average in extracted wood specific gravity.

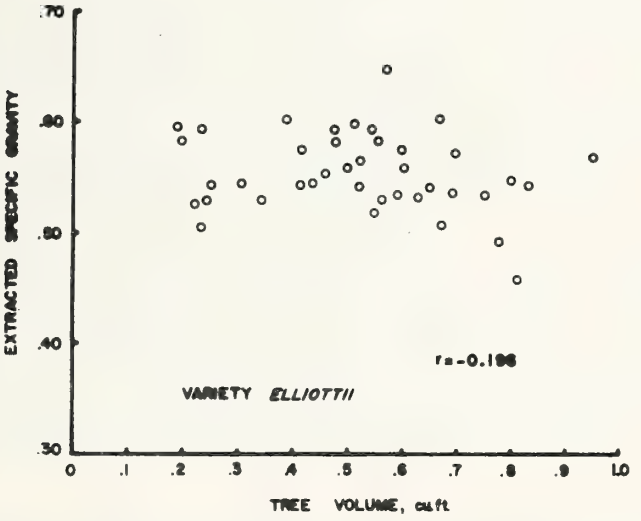

Figure 5.--Unlike variety densa, extracted specific gravity of variety elliottii decreased as tree volume increased.

Individual trees of variety densa varied from 0.1 cubic feet to 1.0; the largest tree had 10 times the volume of the smaller trees and about 2.6 times that of the average tree (Figure 4). Average volume was 0.381 cubic feet. Extracted wood specific gravity increased with tree volume, and had a highly significant correlation coefficient of r = 0.412. This is contrary to the specific gravity and volume growth relationships found in certain studies with other southern pines. The two trees with the largest volume were average or slightly above average in specific gravity. The tree with the highest specific gravity had about 35 percent greater volume than the average tree. If trees with 0.65 cubic-foot volume were selected, they would be about 70 percent larger in size, and from average (0.51) to 14 percent higher in specific gravity. The yield of pulp would be materially increased on a per-acre basis if the traits were inherited. the scatter of points for tree volume in typical slash pine is about the same as for variety densa, except that there were fewer trees in the smaller diameter classes (Figure 5). This may reflect the habit of typical slash pine of making rapid height growth at a younger age than variety densa. Also, the correlation of specific gravity with tree volume differs in typical slash because it is negatively correlated and nonsignificant (r = -0.196). Our data for typical slash pine are in agreement with other studies that show specific gravity decreases as volume growth increases, but the rate of change may be small.

Latewood Percent

Percentage of latewood in the 11-year-old trees averaged 45, but ranged from about 30 to 60 (Figure 6).

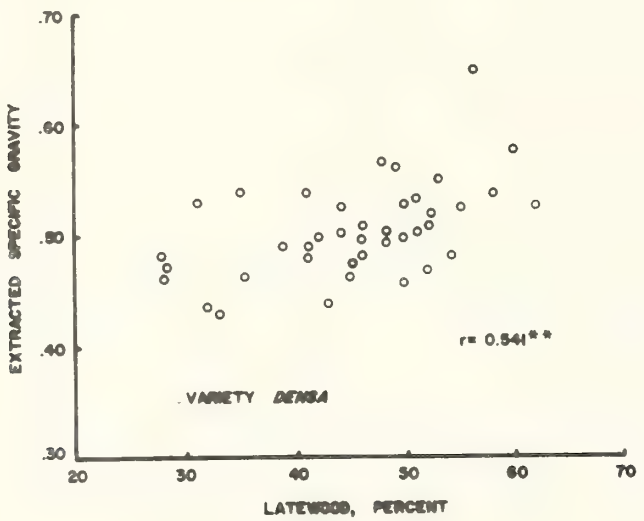

Figure 6.--Latewood percentage values in variety densa ranged from 30 to 60 among the 11-year-old trees, and this contributed to the wide range in specific gravity variation among trees. The relationship of specific gravity to latewood percent was similar to that for typical slash pine, and this was the only trait measured where this was true.

Thus, certain trees had twice the amount of latewood as others, and the highest values were over 30 percent greater than average. Wood specific gravity increased with latewood percent, which is similar to the relationship found in other studies. The correlation coefficient was highly significant ($r = 0.541$). Specific gravity of individual trees varied somewhat among trees with the same percentage of latewood and the range in variation was relatively constant throughout different values. In typical slash pine the scatter of points for latewood percent was similar to that for variety densa. However, instead of being low and negative as for d.b.h., height, and volume, the correlation of specific gravity with latewood was positive ($r = 0.482$) and highly significant. Thus, the relationship of wood specific gravity to latewood percent was similar to that in variety densa.

The percentage of latewood in these young trees did not vary significantly with tree volume for either variety densa ($r = 0.251$) or variety elliottii ($r = -0.120$). This is the main reason why most of the large trees had high dry weight.

DISCUSSION

Applied tree breeding is a creative process. The rate of progress depends on the success with which the breeder selects his parental stock and estimates the gains from the mating scheme used. For breeding stock, the breeder draws on his knowledge of species, races, varieties, and--in many cases--individual plants. In forest tree breeding the choice of the proper individual parent is of great importance because the large size of the plants and great expense of progeny testing make it nearly impossible to use large numbers of trees or base selection of parents upon a very high percentage of populations or families.

Because of the importance of the individual tree, information on intra-specific variation under relatively constant environmental conditions is of considerable value. The range in variation of traits indicates the selection differentials that may be chosen and which rank equally in importance with heritability percent when they are multiplied to give an estimate of genetic gain. Highly accurate information is not easy to obtain because of the extremely wide range of conditions, plus the interactions of ages, stand conditions, and site factors under which trees grow. The alternative is to acquire information from small studies under known conditions such as are reported here.

The trees used in our study were fairly young and certain relationships may change with age, but they are the first figures available for a relatively little-known-but-locally-important tree variety. It was not possible to estimate microsite effects, but broad factors were held constant that have been shown to be important in tree growth and quality, such as age, stocking, and all the complex of temperature, moisture, and soils associated with geographic location.

Tree breeders have pointed out the importance of evaluating trees as a whole rather than becoming involved only in individual traits (Dorman, 1967). Thus, it is necessary to learn the range in each trait and, in addition, the relationship among traits, so that the net effect of all traits on the individual trees can be estimated. This information can best be obtained for

trees grown under the same environment, such as planted stands.

This study, which compares growth rate, wood specific gravity, and survival of the two slash pine varieties when planted at one location in south Florida, is a good example for tree breeders of the additive effects of several rather small differences on total wood produced on an area basis. It will be recalled from our introductory statement that typical slash not only grew faster than variety densa but also had higher wood specific gravity, latewood percent, and plantation survival. For typical slash, a superiority of 9 percent in d.b.h. and 27 percent in height gave a cubic-foot volume superiority of 37 percent. Extracted specific gravity of the wood was 10 percent higher, which brought average tree dry weight to 47 percent more than variety densa trees. Furthermore, survival of typical slash pine was 52 percent higher than variety densa so that total dry weight of wood produced per acre was about 2.2 times that of variety densa. Thus, survival was a large factor in total yield, but might vary from year to year.

Although the differences in performance of the two varieties was quite large, we want to point out, as did White and Saucier (1966), that this is not a definitive study, and foresters should await results of additional studies before revising or completing forest management plans in south Florida.

Assuming that changes in relationships with age will not be very large, which seems to hold fairly well for other southern pines, selection of trees with greatly increased growth rate but normal or improved wood quality characteristics--whichever are desirable--is possible in South Florida slash pine. The positive correlation of specific gravity and volume growth indicates that improvement in yield of dry wood per acre would be striking and prompt if this is a desirable objective.

Inheritance studies with southern pines have shown in many instances that the genotype and the phenotype are highly correlated. This is particularly true if the selection of plus trees was carefully done. This is the reason some slash pine families of superior parents produced nearly twice as much oleoresin as other families (Squillace and Harrington, 1968), or specific chemical composition (Squillace and Fisher, 1966), or high yield of dry wood (Goddard and Cole, 1966), to cite but a few of the important results published to date.

Our study, although small, has given us our first indications of the kind and range of tree-to-tree variations in South Florida slash pine, particularly in the important traits of volume growth and certain wood characteristics. This will make easier the next step of determining the inheritance of important traits and then breeding better trees for the grower and user of South Florida slash pine.

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SESSION II

Genetic Gains and Progeny Test Results

Moderator: Gene Namkoong

From left to right: E.B. Snyder, Gene Namkoong, W.K. Randall, R.E. Goddard, James T. Greene, R.J. Dinus, Bruce Zobel, E. Carlyle Franklin

GENETIC IMPROVEMENT IN FOREST TREES -- GROWTH RATE AND WOOD CHARACTERISTICS IN YOUNG LOBLOLLY PINE

Bruce Zobel, Robert Kellison and Martha Matthias[1/]

FOREWORD

Our assignment is to set the tone for the portion of the SFTIC meeting dealing with gains and improvements in forest trees through use of genetics. This could be done rather dramatically by citation of proper references, because a lot of solid information is now available. But most of you are familiar with results from the tree improvement effort and you will hear many more newer findings at this meeting. Therefore, we will only briefly summarize in general terms overall results and some of the trends for the southern pines; the bulk of this paper will describe volume and dry wood yields, wood differences and the relationship of wood density to growth rate among progeny tests of 43 families in the N. C. State Cooperative Programs. Although the progeny tests were not specifically designed to show gains over commercial planting stock, they illustrate beautifully the differences among families from selected parents for wood density, growth and their interrelationship as well as indicate moisture content and tracheid length variation.

The few generalized remarks regarding gains are drawn from work done throughout the South. They can be summarized as being most encouraging -- gains have been greater and more rapid than any of us imagined would be possible. Overall results have been so good that we no longer have difficulty in "selling" tree improvement, and it is considered operational, not research, by most organizations.

Although growth rate per se has been emphasized by only a few organizations, gains in volume growth have been good, even with relatively mild selection for that trait. Reported results for young plantations (up to 15 years of age) vary from 10 per cent to over 50 per cent improvement in volume growth from first-generation seed orchards. This has been true for both loblolly and slash pines. Even though reasonably good gains in volume have been achieved with relatively mild selection, the really large gains in volume will be expected in second-generation selection for use in improved seed orchards.

Most organizations have emphasized selection for bole form, especially straightness. Gains in this characteristic have been good, with heritabilities in the range of 0.5. It is hard to quantify improvements in bole form but results have been so good that selection for straightness for inclusion in second-generation seed orchards will be very minor.

[1/] Director, Associate Director, and Research Technician, respectively, Cooperative Programs

One of the earliest and most spectacular gains in tree improvement has been in production of naval stores. First- and later-generation progeny produce suitable resins at a rate several times greater than from commercial collections, and these improvements appear to be stabilized as high yield "varieties."

Another really spectacular result has been in resistance to fusiform rust (Cronartium fusiforme). Families have been found that are nearly completely resistant, while others are nearly completely susceptible. Heritability estimates are around 0.8, and mother trees from a given seed orchard may show differences in infection of 60 per cent or more.

Wood qualities, especially specific gravity and tracheid length, have shown high heritabilities, around 0.5 and 0.6, respectively. Although percentage gains are only about 4 per cent when based on the total weight of a cord of wood, the 150 to 300 pounds per cord gain amounts to a large amount of money for all the cords produced on each acre for a large planting program. It is difficult to put values on changes in wood quality due either to changes in specific gravity or tracheid length, but they are considerable under certain circumstances. Research results on the relationship of wood qualities to growth rate make up the bulk of this paper.

Many other tree characteristics such as the ability to survive and grow under adverse environments have responded well to genetic manipulation. "Strains" better adapted to drought, to cold, to ice, to deep peaty soils, etc. are under development and all show promise. Not the least of these is the differential ability of certain families to respond to fertilizers and intensive forest management, a genetic characteristic that must be exploited to the fullest if we are to get maximum yields from each forest acre.

INTRODUCTION

In a forest tree breeding program it is of equal importance to know how growth affects important wood properties as it is to know the inheritance patterns of growth and wood characteristics per se. This paper reports on inheritance of several wood properties and volume growth and their interrelationships for young but merchantable sized trees. The main emphasis of this paper is on the relationship of growth, as expressed in volume, to specific gravity and dry wood weight as produced by fast- and slow-growing families of trees.

Well over 100 papers could be cited on the relationship of growth rate to wood specific gravity.[2/] The lack of general agreement on the relationship of the variables can be partially attributed to the diverse conditions under

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2/ To show the diversity of these studies, a cross section of 12 references, relating to conifers, were chosen for inclusion in the "Literature Cited" section of this paper.

which the studies were conducted. Almost without exception the research results have been for stands of unrelated trees where stand history is unknown and where age, species and methodology used have been confounding factors. For example, the growth rate-wood specific gravity relationship may be quite different for species of Picea and Abies than it is for the hard (Diploxylon) Pinus species, and direct transposition of results from one group to the other cannot be made.

From recent studies it is generally agreed that there is little or no relationship between growth rate and wood specific gravity of merchantable southern pine trees. In direct contrast, weak to strong negative genetic correlations have been reported for young southern pines that have not encountered intraspecific or interspecific competition (Stonecypher and Zobel, 1966; van Buijtenen, 1963; Squillace, et al., 1962). As these authors have cautioned, such correlations indicate that trees with low specific gravity will be obtained if rapid growth rate is exclusively favored; and, similarly, slower growing trees may result if there is a strong selection for high wood specific gravity. Negative genetic correlations found on young trees have led some authors such as Namkoong, et al. (1967) to suggest that inclusion of wood properties in a breeding program may not be advantageous and may even be deleterious. Such conclusions foster the generally believed but unacceptable concept that wood of low density is synonymous with rapid tree growth, irrespective of the stage of development of the tree. As the trees become older the strong negative genetic correlations become insignificant or disappear completely at about the same time as competition among trees starts. 3/ These findings are in agreement with conditions commonly observed in merchantable stands, i. e., one cannot predict wood specific gravity of a tree from an even-aged stand of harvestable southern pines by mere observation of tree size.

Research results reported in this paper are presented to document the inheritance and relationship of growth rate and wood properties for families of trees of known genetic stock. Data are from 3,000 trees, 1,500 of which were felled, and represent actual volume and dry wood weight yields produced in the plantations involved.

MATERIALS

In applied tree improvement programs it is necessary to evaluate the parents used in seed orchards by means of progeny tests. The results from this study are tests for which growth rate and wood properties were accurately determined for trees growing under relatively uniform conditions.

3/ Manuscript in preparation by Stonecypher and Zobel

Four separate plantations supply the data used in this paper.[4/] All were thinned at 7.0 or 7.5 years of age, when full crown closure occurred and wood samples were obtained. In the study reported here, growth is reported by family,[5/] in cubic volume expressed as cords and in tons of dry wood per acre (Table 1). The same volume table (Goebel and Warner, 1962) was used for all plantations. The trees were fast grown, averaging more than five inches in diameter five feet above ground level at 7.5 years of age. Although growth rate of these young plantations is impressive, they are only beginning the period during which maximum average annual yield will be obtained; at culmination there is reason to believe that yield will increase by one-half or greater.

Wood properties were obtained from disks of approximately one inch thickness taken five feet and ten feet above stump height. Specific gravity of the disk was determined in the usual manner, i. e., ratio of dry weight to green volume. For better understanding by the industrialist, specific gravity was converted to pounds per cubic foot and tons of dry wood, and volume was converted to cords of unpeeled wood. A constant factor was used to convert cubic volume to cords, so results of all plantations are comparable. Moisture content of the green wood of trees 7.5 years old and tracheid length of the springwood of the last annual ring were determined from two of the open-pollinated plantations.

The open-pollinated families were represented by four replications of 25 trees (square plots) each from which growth data were obtained. An attempt was made to obtain disks from ten trees of each replication, for a total of 40 trees from each family on which family wood characteristics are based.

The control-pollinated families were in eight-tree rows, with four to six replications (total of 32 to 48 trees per family); approximately one-fourth of these were cut to obtain wood data. Of special interest in the control-pollinated plantation was that all families had the same mother (tree 11-2) but different fathers. The large differences in growth rate and wood properties are attributable to the different fathers, since all came from the same tree, with the only differences being the pollen used.

4/ All plantations are in South Carolina; two are from progeny tests of West Virginia Pulp and Paper Company in the Coastal Plain, one being control-pollinated and one open-pollinated; the open-pollinated Piedmont plantation is owned by U. S. Plywood-Champion Papers, Inc. The other Coastal Plain open-pollinated test is owned by International Paper Company.

5/ A "family" consists of trees from a common parent or parents. An open-pollinated family has a common known mother, whereas a control-pollinated family has both mother and father known.

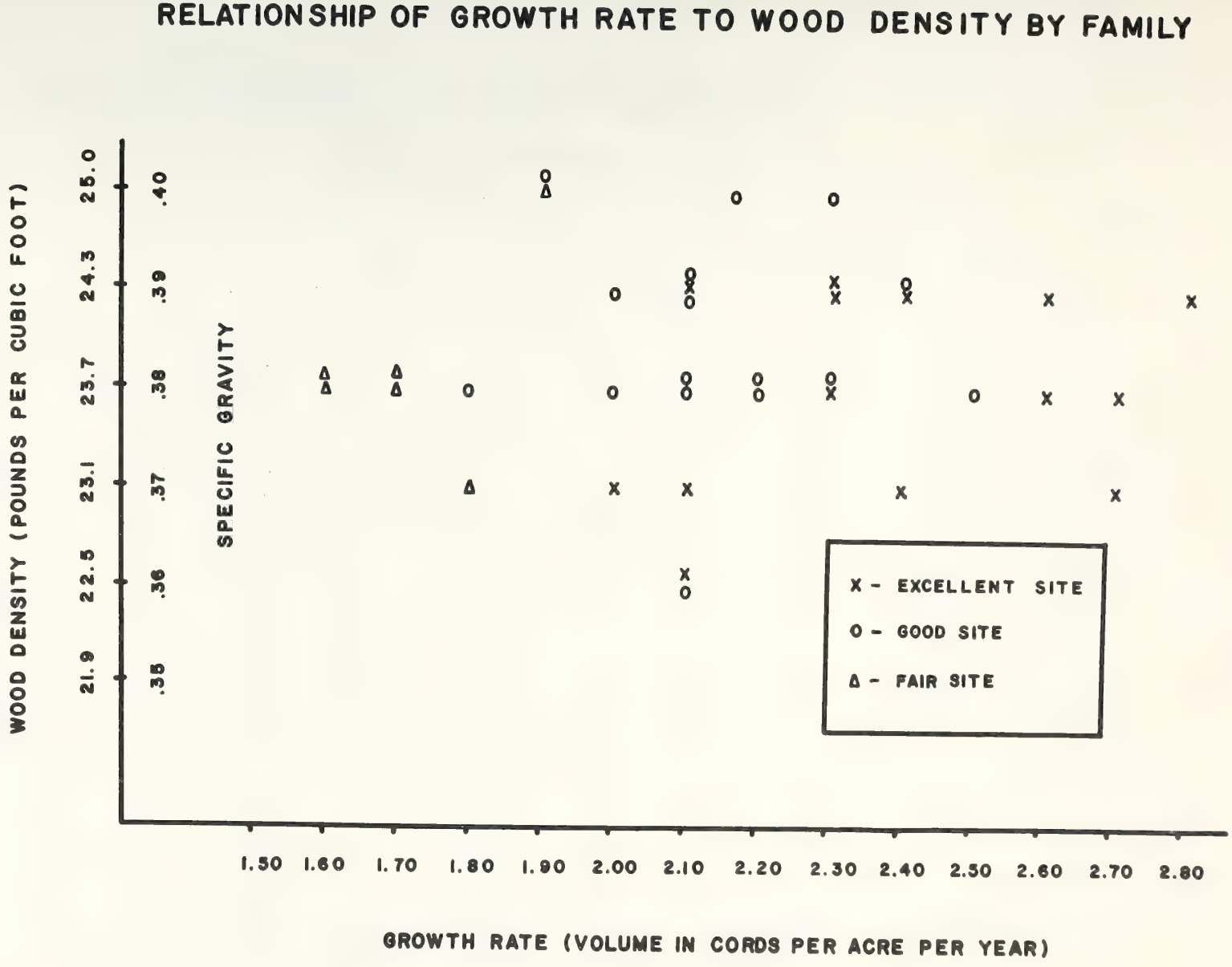

Figure 1. The relationship between growth rate and wood weight (expressed both as specific gravity and pounds per cubic foot) is shown for 43 families from the four plantations under study. There is no obvious relationship between growth rate, expressed either as cords per acre per year or average tree size and wood weight.

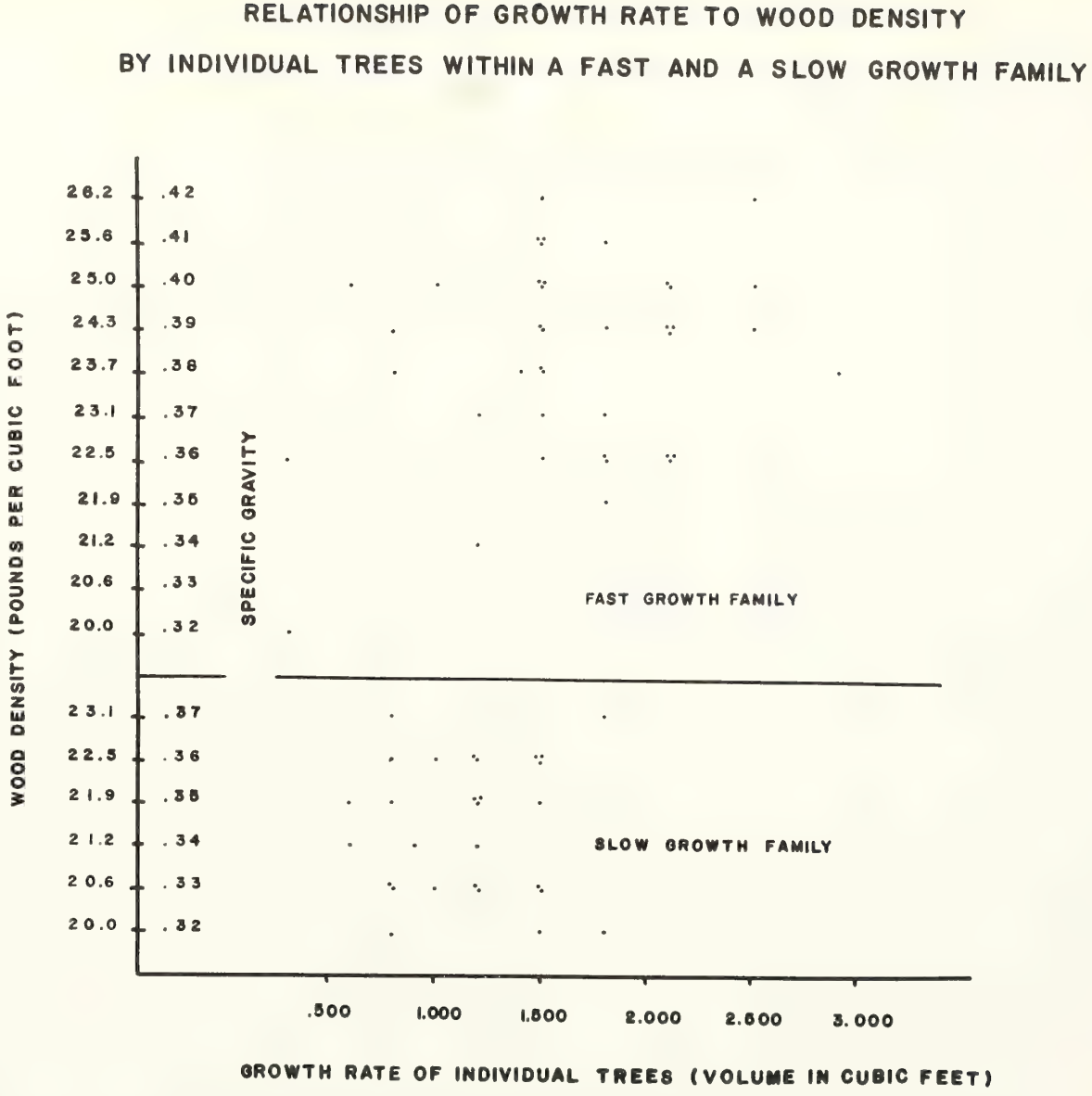

Figure 2. As is always found, there is considerable variability in growth rate and specific gravity among individual trees within a family. Shown are individual tree volumes after seven and one-half years. This spread in values and absence of correlation between growth and wood density is illustrated for two families, one the fastest grown, the other the slowest grown in the good site Coastal Plain plantation.

Table 1. Growth Rate and Wood Properties of Three Open-Pollinated Loblolly Pine Plantations. Data are family averages for trees 7.0 and 7.5 years of age.

Family	# Trees Sampled	DBH (inches)	Height (feet)	Wood Specific Gravity	Wood Weight Lbs./ Cu.Ft.	Cords/[1] Acre/ Year	Tons/[2] Acre Year	Moisture[3] Content	Tracheid[4] Length	Trees/ Acre
(Excellent Site, Old Peanut Field, South Carolina Coastal Plain)										
11-2	40	5.8	33.8	.39	24.3	2.3	2.3	147	3.42	610
11-3	40	5.9	33.4	.39	24.3	2.8	2.7	159	3.58	610
11-7	39	5.8	34.9	.38	23.7	2.6	2.5	166	3.64	550
11-8	36	5.9	32.4	.38	23.7	2.7	2.6	162	3.36	580
11-9	40	6.0	33.4	.36	22.5	2.8	2.5	169	3.40	670
11-10	30	5.9	32.4	.37	23.1	2.1	2.0	168	3.36	540
11-11	40	5.8	35.1	.39	24.3	2.6	2.5	157	3.71	490
11-13	39	5.9	33.1	.37	23.1	2.7	2.5	156	3.47	680
11-14	40	5.7	32.1	.36	22.5	2.1	1.9	171	3.39	600
11-16	39	5.6	34.0	.39	24.3	2.4	2.3	162	3.58	640
11-18	38	5.8	34.9	.39	24.3	2.3	2.2	157	3.71	610
11-19	40	5.7	32.5	.38	23.7	2.3	2.2	157	3.47	650
11-20	40	5.4	32.5	.39	24.3	2.1	2.1	163	3.63	530
11-41	40	5.8	32.2	.37	23.1	2.4	2.3	170	3.28	650
11-51	39	5.6	31.7	.37	23.1	2.0	1.8	170	3.53	580
MEAN		5.8	33.2	.38	23.6	2.4	2.3	162	3.50	600
(Fair Site, Partially Eroded Hill, South Carolina Piedmont)										
3-2	33	4.9	26.8	.38	23.7	1.7	1.6	166	3.29	860
3-4	39	5.2	27.6	.37	23.1	1.8	1.7	171	3.30	830
3-7	38	4.9	26.9	.38	23.7	1.6	1.6	159	3.43	840
3-14	40	5.1	27.0	.38	23.7	1.6	1.5	161	3.29	790
3-16	40	5.3	29.2	.40	25.0	1.9	1.9	149	3.17	820
3-20	40	5.1	26.1	.38	23.7	1.7	1.6	159	3.09	820
MEAN		5.1	27.3	.38	23.7	1.7	1.6	161	3.26	830

(Good Site, Abandoned Field, South Carolina Coastal Plain) 5/

7-2	38	5.2	32.0	.38	23.7	2.1	2.0	--	--	720
7-18	40	5.5	31.5	.38	23.7	2.5	2.3	--	--	810
7-22	39	4.9	30.3	.38	23.7	2.0	1.9	--	--	800
7-29	37	5.1	31.5	.39	24.3	2.1	2.1	--	--	780
7-33	40	5.2	32.1	.38	23.7	2.3	2.2	--	--	810
7-34	40	5.1	33.2	.40	25.0	2.2	2.2	--	--	840
7-43	40	5.2	30.7	.36	22.5	2.1	1.9	--	--	820
7-52	40	5.1	31.7	.39	24.3	2.1	2.0	--	--	780
7-56	40	5.1	33.7	.39	24.3	2.4	2.3	--	--	850
7-58	40	5.1	31.2	.38	23.7	2.2	2.1	--	--	850
7-59	37	5.2	30.8	.39	24.3	2.0	1.9	--	--	740
7-62	40	4.7	30.3	.38	23.7	1.8	1.7	--	--	830
7-67	38	5.0	31.5	.38	23.7	2.2	2.0	--	--	850
7-70	39	4.9	30.7	.38	23.7	2.1	2.0	--	--	850
7-71	39	5.2	32.2	.40	25.0	2.3	2.3	--	--	780
7-72	39	4.8	30.8	.40	25.0	1.9	1.9	--	--	830
MEAN		5.1	31.6	.39	24.3	2.1	2.0	--	--	810

1/ Volumes are actual for trees 7.0 and 7.5 years of age: the excellent and fair sites, 7.5 years; the good site, 7.0 years of age. Therefore, yields are affected by survival (number of trees per acre), disease attack and other items. Apparent discrepancies in volume for families having similar diameters and heights are accounted for by the dissimilar sized distributions within families; volume was determined by individual tree within family, not family mean.

2/ Tons of dry wood. 3/ Based on weight of dry wood. 4/ For the last annual ring.

5/ Moisture content and tracheid lengths were not obtained for these 7-year-old trees.

RESULTS AND DISCUSSION

Growth Rate and Dry Wood Weight

Yield and wood property data have been summarized by open-pollinated families (Table 1) and by control-pollinated families (Table 2). It is obvious from both the open-pollinated and control-pollinated families that growth rate, whether rated by tree diameter or cords per acre per year, was not closely related to wood specific gravity or dry weight per unit volume (Figure 1). For example, family 7-62 had the smallest trees (slowest growth) of the 16 families in its test and had below average specific gravity while family 7-72, nearly as slow-growing, had high specific gravity. Family 7-18, with the largest diameter trees, had below average specific gravity, while family 7-71, which grew nearly as rapidly, produced high specific gravity wood (Figure 2). There were no differences in tons produced per acre per year by these two families (2.3 tons/acre/year) because the lower gravity family survived better, having 30 trees more per acre at time of thinning (Table 1).

Table 2. Growth Rate and Wood Properties for Control-Pollinated Families 1/ -- Loblolly Pine, 7.5 Years of Age 2/ (South Carolina Coastal Plain)

Family	# Trees Sampled (reps.)	DBH (in.)	Hts.	Sp. Gr.	Lbs./ cu. ft.	Cords/ Acre/ Year	Tons/ Acre/ Year	Moist. Cont.	Tracheid Length
11-2 x 11-9	12(4)	5.5	29.2	.35	21.9	2.2	1.9	150	2.93
11-2 x 11-14	8(4)	4.7	27.6	.38	23.7	1.6	1.5	142	2.89
11-2 x 11-18	8(4)	6.1	32.0	.39	24.3	2.9	2.8	136	3.37
11-2 x 11-20	10(4)	5.4	31.2	.40	25.0	2.1	2.2	133	3.36
11-2 x 11-41	18(6)	6.1	32.1	.38	23.7	2.8	2.6	155	3.05
11-2 x 7-34	12(6)	5.9	31.7	.39	24.3	2.4	2.3	141	3.15
MEAN		5.6	30.6	.38	23.8	2.3	2.2	143	3.13

1/ All families had a common mother, with different but known fathers.

2/ The per acre yields are maximum, i. e., with the assumption of full stocking of 680 trees per acre. The field layout did not allow an accurate assessment of the actual wood per acre as was done for the open-pollinated families.

Many similar comparisons could be made. For example, on an excellent site, one of the fastest growing families, 11-2 x 11-41, produced exactly the same specific gravity as the slower growing family, 11-2 x 11-14 (Table 2). In contrast, families 11-9 and 11-14 (Table 1), with the lowest wood specific gravity for their test, 0.36, represent fast and slow growing families, respectively. Based on average tree diameter of families, rather than cubic volume, no obvious relationship between DBH and pounds per cubic foot is shown, the correlation coefficient being r = 0.240 for the good Coastal Plain site and -.309 for the excellent site. These nonsignificant relationships are indicated by family 7-71 which had a tree diameter of 5.2 inches and wood weighing 25.0 pounds per cubic foot and family 7-62 which had a tree diameter of 4.7 inches and wood that weighed 23.7 pounds per cubic foot. Family 11-20 had small trees (diameter 5.4 inches), while family 11-11 averaged 5.8 inches, but both had exactly the same dry wood weight per unit volume.

To further test growth rate and wood specific gravity, correlation coefficients were calculated using individual trees from five families of one open-pollinated progeny test, which represented the fastest, slowest and intermediate growth families. No significant relationship was found between individual tree growth rate and its wood specific gravity for four families, whereas the fifth showed a significant positive correlation (summarized in Table 3). These results support the family mean data based on 40 trees per family, indicating that the fastest growing trees do not necessarily have the lowest specific gravity.

Table 3. Relationship between growth rate and wood specific gravity of individual trees within families

Family	No. of Trees Within the Family	Correlation Coefficient Between Growth Rate and Specific Gravity of Tree	Statistical Significance
7-59	37	+.143	N.S.
7-18	40	+.184	N.S.
7-2	38	+.151	N.S.
7-62	40	+.007	N.S.
7-29	37	+.447	**
All 5 families combined	192	+.014	N.S.

** Significant at the 1% level

Although only six families were involved in the control-pollinated progeny test (total of 68 trees harvested of the 262 measured), the variation in wood properties and growth rate and the lack of relationship of growth rate to wood specific gravity is very pronounced (Table 2). The fastest growing cross (11-2 x 11-18) produced 1.3 cords per acre per year more than the slowest growing cross (11-2 x 11-14) while still producing somewhat more dense wood, 24.3 versus 23.7 pounds per cubic foot.

Yield of Dry Wood Substance

When discussing dry wood weight yields it is necessary to keep the proper perspective. An increase in wood specific gravity will improve yields in tons per acre but much greater tonnage yields can be obtained by increasing volume growth. We as plant breeders look at any change we can obtain in specific gravity as "cream on the milk" but we all recognize the best way to increase total production is to increase the amount of volume (Figure 3). In general, a difference in specific gravity of 0.02 on a two cord per acre per year volume production will mean a weight difference of 0.1 ton of dry wood per acre per year. However, an increase of 0.2 cords per acre per year will mean a difference of 0.25 tons per acre per year of wood produced (See Table 1). For this study, maximum family differences in wood specific gravity were 0.04 but it is not unusual to have growth rate differences among families as great as 0.6 cords per acre per year.

Volume production is controlled by growth rate of the individual trees, by per cent stocking, and by the number of destructive agents present. For example, in the good Coastal Plain plantation, family 7-62 with good stocking gave low tonnage yields because it grew slowly, whereas family 7-18 produced 0.6 tons more wood per acre per year because it was a faster grower even though it had twenty less trees per acre. As another example, family 11-8, with 580 trees per acre, produced an equal volume of wood on an acre, as did family 11-13 which retained a stocking of 680 trees per acre. The prevalence of Cronartium fusiforme and other destructive agents will reduce yields considerably although this is not readily indicated by the number of trees per acre.

It is obvious from the 37 open-pollinated and 6 control-pollinated families studied here that individual tree growth rate, wood specific gravity, or survival cannot alone be a good predictor of dry wood weight yields. The only uncontested result is a direct measurement of dry wood weight on the plantation, which requires accurate determination of both volume and weight of wood per unit volume. No matter how it is obtained, the largest quantity of most desirable fiber is the objective of tree improvement programs, and this can be achieved best by improving growth and wood qualities simultaneously, as seen by the 43 families in the four plantations studied.

Under current conditions, loblolly pine of either low or high specific gravity wood may be preferred, depending on the product produced. To attain this objective the breeder must aim for fast growth plus control of the kind of wood desired. Because of the lack of relationship between growth and specific gravity on either a family or individual tree basis, the breeder should

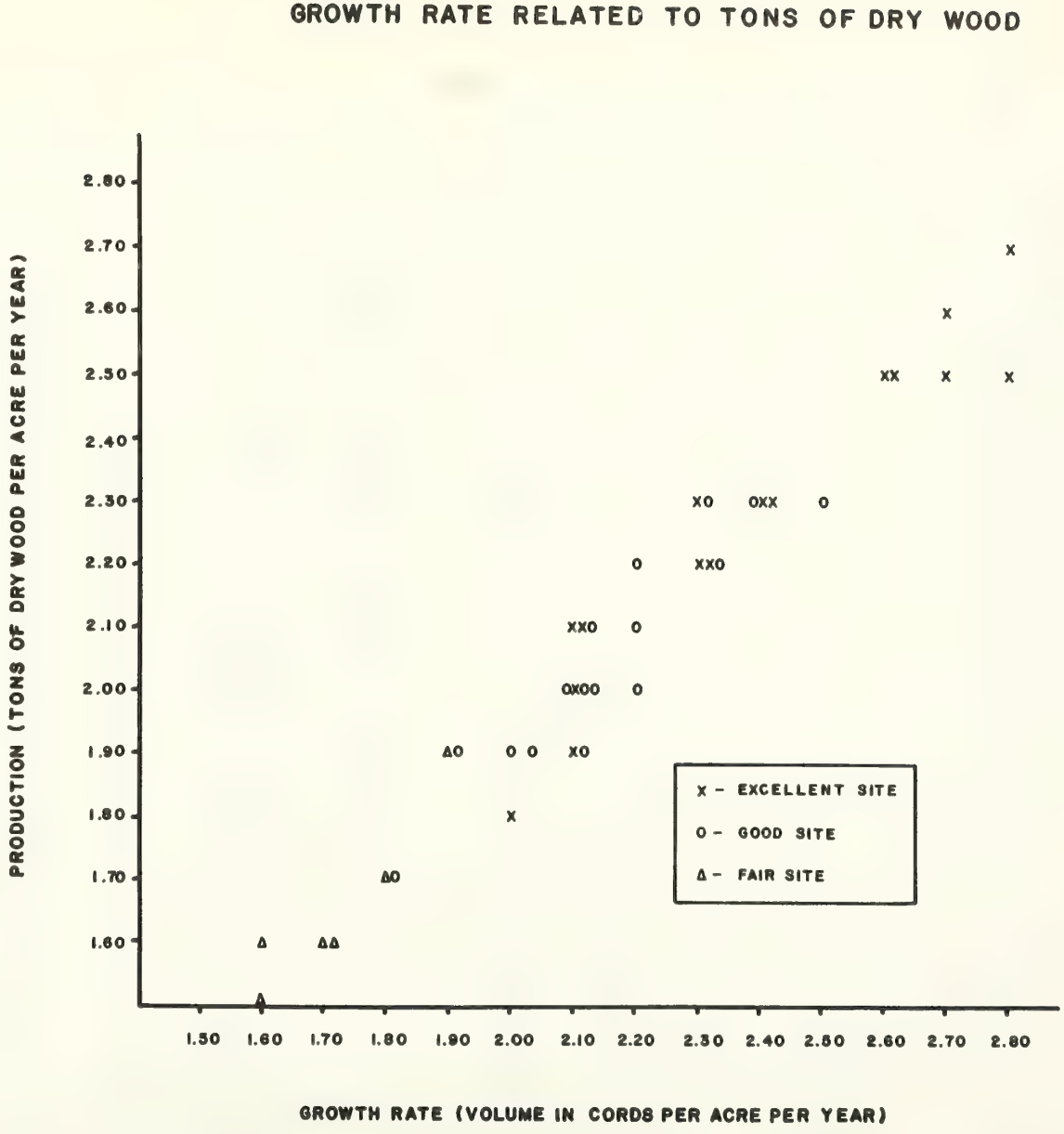

Figure 3. Growth rate in cords per acre year year is plotted against production rate in tons per acre per year, illustrating the close relationship between tonnage yields and increasing volume growth.

attempt to obtain gains in both, and neither wood quality nor growth rate need be sacrificed for the other.

Moisture Content and Tracheid Length

Differences in amount of water per unit of dry wood in different families are quite outstanding. For example, family 11-2 had 1.5 pounds of water per pound of dry wood while family 11-14 had 1.7 pounds of water per pound of dry wood. Both families were the same age, both slow growing, but the former had high gravity, the latter low gravity. A similar range of moisture contents by family was found even among the six families in the fair Piedmont site. In the control-pollinated test (all families which had the same mother) there was a strikingly high difference of 133 to 155 per cent moisture content among the six families.

To the authors' knowledge this is the only time that inheritance of moisture content *per se* by family has been reported. The differences found at this young age (7.5 years) will probably increase as specific gravity and moisture contents diverge as the trees become older.

It has been commonly observed that within a species, higher specific gravity is associated with a lower moisture content. This relationship, plotted in Figure 4, is quite good, the trees having the highest dry weight of wood per unit volume having the lowest moisture contents.

Tracheid lengths varied considerably by family but were not related to growth rate. In the open-pollinated families from the excellent site, tracheid lengths varied nearly 0.5 mm, a greater spread than one would expect from families of trees of this young age growing on the same site. Approximately the same range of lengths was found among the six control-pollinated families.

As an aid to those proposing short rotations or use of young thinnings, complete summary data from this study are reported below (Table 4). This is a good idea of the kind of wood to be expected from young loblolly pine.

Table 4. Wood properties for 7.0- and 7.5-year-old loblolly pine are summarized by plantation to help give an idea of the kind of wood obtained from young thinnings.

	No. of Trees	Lbs/cu.ft. (Dry Weight)	Moisture Content (Based on Dry Weight)	Tracheid Length (7th ring)
Excellent Site (Coastal)	581	23.6	162	3.50
Good Site (Coastal)	626	24.3	-	-
Fair Site (Piedmont)	230	23.7	161	3.26
Excellent Site (Coastal) (Control-pollinated -- 1 common female parent)	68	23.8	143	3.13

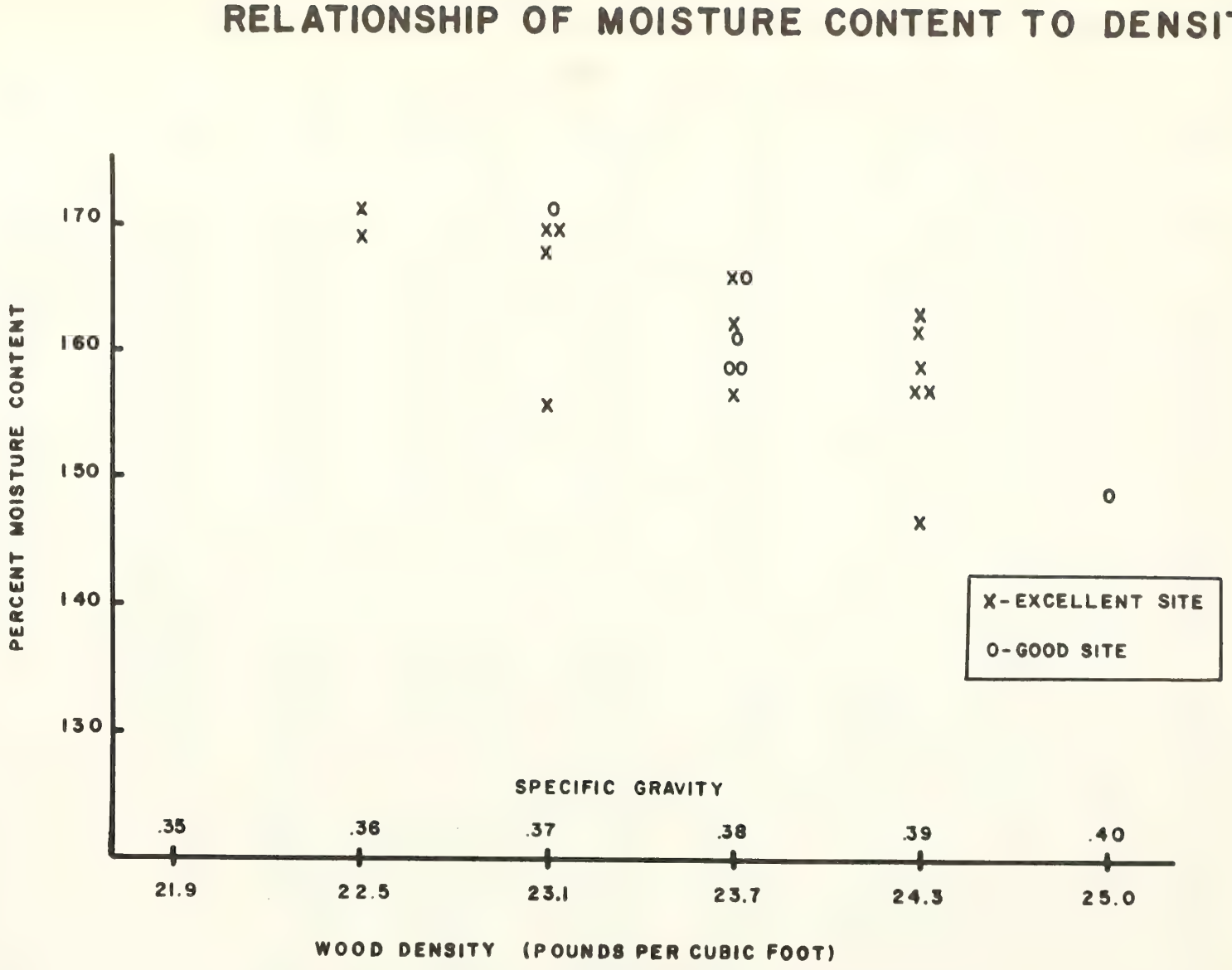

Figure 4. There usually is a good (negative) relationship between wood density (specific gravity) and moisture content. Averages of wood weight are plotted against moisture content (based on dry wood) for 21 families analyzed. Note the lower moisture contents for the families with higher wood densities.

Inheritance of Wood Weight and Moisture Content

Wood qualities among families were constantly and statistically different, indicating that trees of the same age growing at the same spacing produce quite different kinds of wood. Although the six families are too few from which to draw sound conclusions in the control-pollinated test, it appears to be more than chance that the very low gravity family (11-2 x 11-9) has inherited light wood from parent 11-9, which produced a very low gravity open-pollinated family. Conversely, 11-2 x 11-20 had high wood specific gravity, which might be expected since 11-20 was one of the highest of the open-pollinated families. The common parent in both crosses (11-2) had slightly higher than average specific gravity when tested as an open-pollinated family.

Parent 11-2 used as the mother of all families in the control-pollinated test had low moisture content and all crosses with this tree had low moisture (143 per cent compared to 162 per cent for the average of all open-pollinated families of the excellent Coastal Plain site with which it occupied adjacent plantations). There are too few data for absolute proof but it would be difficult to explain the low moisture content of the control-pollinated families if it were not that the one common parent 11-2 had the lowest moisture content of all open-pollinated families, and this was reflected in control-pollinated families.

SUMMARY

Wood weight, moisture content and tracheid length, plus rate of volume growth, were determined for 1,500 young (7.0- and 7.5-year-old) progeny from seed orchard parents, grown on three different sites. Wood specimens were obtained as thinnings from 43 families from the three open-pollinated and one control-pollinated plantations.

1. Relationship between growth rate and wood specific gravity was nonexistent. Some fast growth families had heavy wood, some light. The fear that fast growing families will produce only low gravity wood is unfounded; it is possible to breed for rapid growth without sacrificing high wood specific gravity. In fact, the nonsignificant correlations between wood specific gravity and growth rate for trees harvested would indicate the necessity of making simultaneous selections for both growth and wood density.

2. A worthwhile increase in wood production per acre can be obtained by increasing wood specific gravity, but increased tonnage yields can be more easily produced by an increase in volume growth.

3. Differences among families growing under uniform conditions within plantations were considerable for both wood moisture content and tracheid length. Low moisture content parents produced low moisture

in both open- and control-pollinated progeny. A strong relationship exists between low wood density and high moisture content. No relationship was evident between wood density and tracheid length.

4. Growth rate and dry wood production were remarkably high for plantations only 7.0 or 7.5 years old; the best family grew at the rate of 2.8 cords per acre per year or 2.7 tons of dry wood per acre per year. Although all families were from selected trees used in seed orchards, wood yield differences were very great. For example, in the plantation on the best sites, dry wood produced varied from 1.8 to 2.7 tons per acre per year for the best and poorest families.

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PROGENY TESTING FOR INTENSIVE MANAGEMENT

R. E. Goddard and W. H. Smith[1/]

Trends in commercial forestry in the South are towards intensification of forest management. Rising taxes, soaring wages, increases in mill capacity, reduction of land area devoted primarily to timber production, and mechanization of forestry practices from planting to harvest force us to seek maximum yields from managed forests.

Programs for forest tree improvement are one phase of this effort to produce more and better timber per acre. Similarly to produce more wood, intensive silviculture is now the rule rather than the exception. Conversion from natural to planted stands, site preparation prior to planting including bedding of thousands of acres, and water control are common practices. A procedure not yet used on an appreciable scale is application of chemical fertilizers to planted stands. Forest fertilization can be expected to expand rapidly as forest-soil fertility is understood and as procedures and prescriptions are developed.

The parallel development of genetic improvement and intensification of cultural measures we are experiencing in plantation forestry is similar in many respects to the agricultural explosion during the 20 century. An example is hybrid corn. Although there were several decades of prior development, widespread acceptance of hybrids by farmers did not begin until about 1940. Current corn yields per acre are many-fold higher than 30 years ago. However, the genetic improvement of corn and modern farming practices are so closely meshed that the effects of genetics and cultural practices cannot be separated. We can expect a comparable compounded progress in forest trees with the greatest gains achieved by development of strains that take fullest advantage of improved cultural practices.

GENOTYPE X ENVIRONMENT INTERACTIONS

The differential response of various genetic entities to changes in environment, or in statistical terms, the genotype X environment interaction, is a common biological phenomenon and can be expected to occur with forest tree species. This is one of the main reasons for establishing geographic seed source studies. The sources best for planting in Florida may not be the best for use in Texas. A study established in 1965 in the Florida cooperative program illustrates some interactions between progeny lines and general environment.

Seed from approximately 90 slash pine clones were collected in seed orchards. Some 12 geographic areas within the natural range of slash pine were represented by up to 12 ortets (mostly 5-10 ortets per area). (See Figure 1). In January 1965, outplantings were established in Alachua County, Florida, Baldwin County, Alabama, and Long County, Georgia. Site preparation in each location was standard practice for the area and in no case was particularly thorough. The Florida and Georgia sites are flatwoods and had a single harrowing plus bedding. The Alabama site is rolling hillside and was only

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[1/]Associate and Assistant Professor, respectively, University of Florida, School of Forestry, Gainesville, Florida.

1. George-Jackson, Miss.
2. Escambia-Santa Rosa, Fla.
3. Holmes-Calhoun, Fla.
4. Taylor-Dixie, Fla.
5. Madison-Hamilton, Fla.
6. Nassau-Duval, Fla.
7. Atkinson-Clinch, Ga.
8. Charlton-Camden, Ga.
9. Brantley, Ga.
10. Wayne, Ga.
11. Telfair-Appling, Ga.
12. Worth-Turner, Ga.

Planting Sites

A. Baldwin, Ala.
B. Alachua, Fla.
C. Long, Ga.

Figure 1.--Ortet locations and outplanting sites for slash pine select tree provenance trials.

chopped although a front-end blade was used to clear away debris during the planting operation. Because of variable quantities of seedlings available, it was not possible to establish all progeny lines at each planting site, but 30 lines are common to all sites.

Table 1.--Mean third-year height on three test sites by area of ortet location

Alachua, Florida Test Site			Baldwin, Alabama Test Site			Long, Georgia Test Site		
Ortet Location	No. of progeny lines	mean ht. (ft)	Ortet Location	No. of progeny lines	mean ht. (ft)	Ortet Location	No. of progeny lines	mean ht. (ft)
5	4	4.5	1	7	4.6	7	7	4.1
4	7	4.2	9	3	4.6	8	5	4.0
8	4	4.1	7	7	4.6	1	6	3.9
6	10	4.0	8	5	4.5	10	9	3.8
7	8	3.9	11	7	4.3	9	2	3.8
9	9	3.8	6	9	4.3	6	7	3.8
11	9	3.7	4	1	4.2	4	5	3.8
10	12	3.6	3	4	4.1	11	7	3.7
12	6	3.5	10	10	4.1	5	3	3.7
1	10	3.5	12	1	4.1	3	3	3.6
2	7	3.3	2	6	4.0	2	2	3.5
3	6	3.3						

Total tree heights three years after establishment were measured in January 1968. Results at this stage indicate some effect of ortet location (Table 1). At the Alachua County site, trees from the nearer areas grew better on the average than trees of more distant origin. The same trend was true for the Georgia and Alabama sites, except for the poor performance of West Florida trees on all sites and the good growth of Mississippi progenies on both Alabama and southeast Georgia sites.

When individual progeny lines are examined, it is obvious that variation within provenances is far greater than differences between provenance averages. The performance of individual lines at the three test sites shows little relationship to ortet location. In Table 2, the dozen lines at each site with

Table 2.--Progeny lines with greatest mean third-year height on three test sites

Alachua, Florida Test Site			Baldwin, Alabama Test Site			Long, Georgia Test Site		
Ortet Location	Progeny line	mean ht. (ft)	Ortet Location	Progeny line	mean ht. (ft)	Ortet Location	Progeny line	mean ht. (ft)
5	222-56	5.3	9	263-56	5.7	8	265-55	5.3
6	106-56	5.3	7	143-56	5.5	7	89-56	4.9
5	283-55	5.0	1	89-57	5.3	7	16-57	4.6
4	248-56	4.9	1	34-58	5.3	1	88-57	4.4
6	262-55	4.8	11	38-56	5.3	10	240-55	4.4
11	11-57	4.8	7	89-56	5.1	10	286-56	4.3
4	1-56	4.7	6	113-56	4.9	1	89-57	4.2
8	97-56	4.5	1	41-58	4.8	5	222-56	4.2
7	16-57	4.4	7	87-56	4.8	7	87-56	4.2
10	33-56	4.4	8	97-56	4.8	6	121-56	4.1
6	114-56	4.3	8	100-56	4.7	11	77-56	4.1
7	48-56	4.3	10	235-55	4.7	4	1-56	4.0

greatest mean height are listed. Some individual lines from distant sources grew faster than many relatively local lines. Also, several lines are among the top performers at two different test locations.

Analysis of variance involving the 30 lines planted on all three sites (Table 3) indicated highly significant differences among all major effects, i.e. sites, provenances, and lines within provenances. In addition, the provenances X sites and the lines within provenances X sites interactions were significant. This later interaction indicates that all lines within a provenance did not react to site differences in the same manner. Some lines grew well in only one location while others showed very satisfactory growth at all sites.

In older slash pine progeny tests there is good correlation (r=.88) between third year progeny mean height and fifth year volume (Goddard and Strickland, 1968). Thus, if the various progeny lines continue development in the pattern indicated in these tests, clones for a slash pine orchard for any specific area can be selected from much of the species range and need not be

limited to the area served by the orchard. However, the specific clones that will produce the best-growing planting stock for an area must be determined by progeny tests. Orchards established on the basis of progeny-test results should achieve improvement substantially above current orchards.

Table 3.--Analysis of variance. Third year height of 30 slash pine progeny lines on three sites

Source of variation	Degrees of Freedom	Mean Square
Sites	2	23.90**
Lines	29	4.19**
Provenances	10	5.66**
Lines/Provenances	19	3.42**
Lines X Sites	58	1.89**
Provenances X Sites	20	1.13*
Lines/Provenances X Sites	38	2.29**
Experimental Error	27	.48

* Significant at 5% level of probability.
** Significant at 1% level of probability.

GENOTYPE X CULTURAL TREATMENT

Just as various groups of genetically related plants react differently to changes in climatic, edaphic and other factors of the general environment, comparable interactions with cultural treatments occur. Studies of differential responses of slash pine lines to cultural measures have been underway for several years in the University of Florida cooperative program. The first, established in 1961, included fertilization, irrigation, cultivation and seed parent as variables and has been previously reported (Pritchett and Goddard, 1967). In this study, magnesium ammonium phosphate was applied annually to individual trees, irrigation was applied during spring and fall dry periods and cultivation consisted of light rototilling between rows.

All treatments had significant effects on tree growth, particularly during the last two years of the five-year study. Irrigation increased mean total height at five years by 2.9 feet and d.b.h. by 0.6 inches. Cultivation increased average total growth to a smaller but statistically significant amount. Fertilization affected growth significantly only the last two years--total height averaged 0.3 feet less on fertilized plots.

The small average response to fertilization can be largely attributed to the highly variable response of individual progeny lines. Total height response of individual lines varied from -2.3 to +2.8 feet. During the last two years response varied from -0.8 to +1.8 feet in height growth and -0.14 to +0.92 inches in diameter growth.

There were also significant interactions between progeny lines and irrigation. All lines responded positively but line differences in height growth during the final two years between irrigated and non-irrigated plots varied from 0.5 to 3.0 feet. These results imply, as do results of the geographic source test discussed above, genetic variation in environmental requirements or in degree of response to more favorable conditions.

FERTILIZATION TRIALS

The cultural treatment of pine plantations most likely to find wide application, other than intensive pre-planting site cultivation, is fertilization. For this reason, continuing emphasis was placed on distinguishing progeny lines which show a strong positive response to added nutrients. A trial of this type was planted in 1963, with eight-tree rowplots of 15 select progeny lines and 3 control lots established in 10 blocks. In 1964 and again in 1965, 300 pounds per acre of diammonium phosphate (18-56-0) were applied to half of each block.

From measurements recorded at age 5, dry weight of bole wood inside bark was determined. Mean dry weight per tree on fertilized plots was 4.5 pounds as compared to 4.1 pounds without fertilizer, not significantly different. Again, the average effect of fertilizer was obscured by highly varied responses of the individual lines (Table 4). Response by lines varied from

Table 4.--Mean dry weight per tree at 5 years in fertilized and unfertilized plots by progeny line

Progeny line	Mean dry weight per tree (lbs.)		
	unfertilized	fertilized	response
240-55	4.7	4.8	0.1
244-55	5.2	6.5	1.3
254-55	4.5	4.5	0.0
284-55	3.8	3.7	-0.1
289-55	4.3	4.2	-0.1
60-56	4.1	5.2	1.1
67-56	4.2	5.0	0.8
110-56	5.0	4.5	-0.5
121-56	3.6	4.6	1.0
269-56	3.5	4.0	0.5
18-57	3.4	3.7	0.3
21-57	4.6	4.6	0.0
60-57	4.1	4.9	0.8
67-57	4.3	4.7	0.4
89-57	4.1	3.8	-0.3
Controls	3.7	4.2	0.5
Mean	4.15	4.51	.36

-10% to +25% of weight of trees in untreated plots. Five of the select progeny lots showed a relatively strong response to the added fertilizer, one showed a negative response and the remainder of the lots were little affected by treatment.

In 1967 a screening program was initiated with the goal of determining the reaction of progenies of all slash pine clones used in the Florida program to nitrogen and phosphorus. Blocks were laid out and divided into four plots each. Treatments randomly applied were untreated control, N, P, and NP. Both N and P were broadcast at the rate of 50 pounds per acre and lightly tilled into the soil prior to planting. Sub-plots consisted of individual progeny lines planted at 2 X 2-foot spacing. Three annual measurements were planned.

Grass and weeds responded so vigorously to fertilizer treatments the first year that effects on tree seedlings were obscured. In 1968 plots were planted at 1 X 4-foot spacing and vegetation between rows controlled by light tilling twice during the growing season. To establish the 1968 study, seed of 60 progeny lines were planted in small peat pots and seedlings transferred to the field after they became well established. At the same time, to see if the screening trials could be shortened, freshly germinated seedlings of the same lines were established in half-gallon milk cartons, fertilized at rates comparable to the field test and retained in a greenhouse.

Basal diameters and heights of seedlings in the 1968 field and greenhouse studies were measured after one year and these measurements used to compute seedling volume, assuming the stem to be a right cone. Data on height, diameter and volume were subjected to analysis of variance.

Treatments, averaged over all lots, had significant effects on height growth in the field plots and on diameter and volume in the greenhouse (Table 5). Most of the treatment effect was due to nitrogen (Table 6) although the

Table 5.--Summary of results of statistical analyses of measurements of year-old slash pine progenies under 4 fertilization treatments

Source of Variation	Greenhouse			Field		
	Height	Diameter	Volume	Height	Diameter	Volume
Treatments		**	**	*		
N_0 vs N_1		**	**	**		
P_0 vs P_1		*	**			
N X P			*			
Lines	**			**	**	*
Lines X Treatments	**					

* Means different at 5% level of probability.
** Means different at 1% level of probability.

Table 6.--Measurement means of year-old slash pine seedlings by treatment in field and greenhouse

Treatment	Height (cm)		Diameter (mm)		Volume (cc)	
	Greenhouse	Field	Greenhouse	Field	Greenhouse	Field
Control	18.7	17.9	2.8	4.4	0.4	1.2
N	18.3	24.3	2.9	5.8	0.4	2.3
P	18.7	20.5	2.9	5.6	0.4	2.1
NP	18.0	24.2	3.2	5.7	0.5	2.5

influence of phosphate can also be seen. Diameter increment was increased by N in both field and greenhouse. The field design was a split plot experiment and consequently of low sensitivity in detecting differences among the major treatment plots although trends are apparent.

There were significant differences among progeny lines in all traits measured in the field test, but lines varied significantly only in height growth in the greenhouse. Individual lines varied in volume from 0.83 to 4.74 cc in the field and from 0.32 to 0.64 cc in the greenhouse. Field grown seedlings had substantially larger diameters than greenhouse seedlings.

The major objective of the trials was determination of differential responses to fertilization. A significant line X treatment interaction was observed only with height growth in the greenhouse. In this case, response of individual lines varied so much as to nullify over-all treatment effects (Table 7).

Table 7.--Example of lines showing opposite response to nitrogen

	mean ht. (cm)				
line	Control	N	P	NP	mean
A	26.2	14.7	30.0	27.7	24.7
B	13.9	27.9	18.2	32.2	23.1

Examples of varying response to treatment in other attributes measured were found in both greenhouse and field tests but the interactions were not statistically significant.

Correlation coefficients between field and greenhouse volume means for each line under the four treatments were calculated. No relationship between the relative field and greenhouse performance of progeny lines was indicated (Table 8). Lines failed to react similarly to treatments in the two locations. This may relate to pathogen problems encounted in the greenhouse.

Table 8.--Correlation between mean volume per line in field and greenhouse trials

Treatment	r
Control	0.014
N	-0.026
P	0.142
NP	-0.163
All	0.104

Establishing seedlings in fertilized, unsterilized, potted soils proved difficult because pathogens seemed to be favored by the nutrients. This fact accounted for much of the variability among and within lines. For example, one line had to be discarded because of its high susceptibility to damping-off. Techniques are under development for avoiding this problem during the highly susceptible period of seedling development. Techniques of interest concern soil sterilization and re-inoculation with mycorrhizae cultures and fertilizing after seedling establishment. Further it is believed that a single "optimum" fertilizer treatment should be chosen for screening trials

such that experiments are not limited by inadequate replication and physical problems. For example, this greenhouse experiment involved 900 pots but only 3 replications.

Results to date in attempts to screen numerous lines for response to fertilizer have not suggested any short-cut procedures. However, nutrient accumulations, which are to be determined, may represent variable reserves for growth in a second year. Experience with older tests indicates that three years or more may be needed to show definite differential responses to treatments in field tests. The lack of relationship between field and greenhouse performance does not encourage reliance on short-term pot trials. Hopefully, observation for three years in the intensive field plots and refinement of short-term techniques will provide a means of identifying progeny lines responsive to fertilizer treatment. With so many lines in hand, the task will not be simple. However, only a few lines identified as responsive can be considered a success.

SUMMARY

Results of several tests suggest that slash pine lines vary in their responses to different natural and culturally altered environments.

Variation within geographic areas is greater than variation between areas. Lines from relatively distant sources may grow as well or better than lines from local selections.

Differential response to cultural measures such as fertilization, detected in field tests 3-5 years old, were not strongly indicated by simple measurements of year-old seedlings. Greenhouse performance of lines was not related to growth in the field. These results indicate that present short-term screening trials to determine superior response to fertilization have not proven reliable and longer field trials may be required.

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PARENTAL SELECTION VERSUS HALF-SIB FAMILY SELECTION OF LONGLEAF PINE

E. Bayne Snyder[1/]

Longleaf pine (Pinus palustris Mill.) differs from other southern pines in that it grows very slowly in height during the first few years. The speed with which longleaf seedlings come out of this grass stage will be important to any program for genetic improvement of the species. This study reports variation in open-pollinated progeny relative to parental ratings established by use of comparison trees. It indicates that both progeny-test selection and phenotypic selection for early height growth will be effective.

METHODS

In 1955, wind-pollinated seeds were collected from 100 randomly selected trees in Harrison and two adjacent counties in southern Mississippi. These trees and three comparison trees near each were measured. Comparison trees were on the same sites and were approximately equal to the parent trees in age, as determined from increment cores, and in diameter. Heights were measured to the nearest foot and diameters to the nearest 0.1 inch. Seeds were weighed.

In 1956, 21 seeds from each tree were sown in each of six nursery replications which were arranged in a 10×10 triple lattice design. In the spring of 1957, the seedlings were lifted and their average green weights determined.

Immediately prior to planting, a previously cleared 8.5-acre area was burned. The seedlings were planted on it at a 6- by 12-foot spacing. For outplanting, the number of seedlings per plot was reduced to eight. The plantation was periodically mowed and brown-spot infection was effectively controlled by spraying. The trees were measured after 5 years, when most of the seedlings were coming out of the grass stage. They were measured again after 8 years in the field, when they had assumed a more even growth pattern.

Since few or no trees survived in some of the plots, missing plots presented an analytical problem. This was solved by a computer program applicable to lattice designs which yields unbiased means and sums of squares for randomized complete blocks (Goulden 1952; Homeyer et al. 1947). Adjusted means, adjusted family mean squares, and average effective mean squares for error provided by the lattice design were used in the computations. Within-plot variances were derived from a 10 percent random sample of the plots. Tests of significance are at the 0.05 level.

RESULTS AND DISCUSSION

Seed and seedling weight.--It was assumed that large seeds would produce large nursery plants, which, when outplanted, would rapidly come out of the grass. Initial analyses disclosed that there were significant differences in green weight per lifted seedling ranging from 16 to 28 grams. Furthermore, the green weight depended in a positive and significant manner on seed weight, which varied from 66 to 132 g./1,000. The regression was:

$$\text{green weight} = 14.49 + 0.084 \text{ (seed weight)}.$$

1/ The author is stationed at the Institute of Forest Genetics, Southern Forest Experiment Station, USDA Forest Service, Gulfport, Mississippi.

The regression coefficient is statistically significant; the standard error is 0.012 and R^2 is 0.26. The data indicate that green weights of nursery seedlings may be increased an average of 25 percent over the smallest seeded families by selecting the largest seeded families.

After 8 years in the field, however, neither seed weights nor seedling weights at planting time were related to height. Perhaps the nursery advantages were, in part, lost in transplanting.

Sib analyses and heritabilities.--Analyses of variance showed that family differences in survival and height growth were statistically significant. Mean field survival at 5 years was only 59 percent. Survival of the best 75 families ranged from 48 to 83 percent and did not differ significantly according to Duncan's range test. The lowest family survival was 22 percent. The mean 8-year heights of the best 20 families varied from 7.1 to 10.2 feet; differences among these families were not statistically significant. Heights of the three best families, however, averaged 10.2 feet at 8 years, compared to 5.8 feet for the population mean and 0.7 foot for the poorest entry.

Components of variance and heritabilities based on individuals and plot means were estimated from mean square components:

Source of variation	Expected components	
	Individual trees	Plot means
Families	$\sigma_w^2 + 4.567\ \sigma_{rf}^2 + (4.606)\ (4.567)\sigma_f^2$	$\sigma_e^2 + 4.606\ \sigma_f^2$
Error	$\sigma_w^2 + 4.567\ \sigma_{rf}^2$	σ_e^2
Within plot	σ_w^2	...
Heritability	$h^2 = \frac{4\ \sigma_f^2}{\sigma_w^2 + \sigma_{rf}^2 + \sigma_f^2}$	$\frac{4\ \sigma_f^2}{\sigma_e^2 + \sigma_f^2}$

Standard error of $\sigma_f^2 = \sqrt{\frac{2}{C^2}\left(\frac{M.S._1{}^2}{D.F._1+2} + \frac{M.S._2{}^2}{D.F._2+2}\right)}$ (Anderson and Bancroft 1952)

C is the coefficient of the σ_f^2 component, and M.S. and D.F. are the mean squares involved in calculating the component along with their degrees of freedom. In calculating mean square components of heights for individual trees, the plot mean squares were first multiplied by 4.567, the harmonic mean number of plants per plot. The coefficient 4.606 is an approximation, calculated by Federer's (1951) method, to account for missing plots. Heritability estimates are shown in table 1.

Parent-progeny analyses and heritabilities.--Adjustments for age and site were applied to both parental diameters and heights prior to correlation with progeny height (table 2). Adjustments for age were made by dividing diameter and height by the age of the tree and expressing the results as mean annual diameter or mean annual height growth. Adjustments for environment were made

Table 1.--Sib analyses components of variance and heritabilities for 5-year survival and height and for 8-year height

Character	Components				Reliability ratio[1/]	Individual heritability	Plot heritability
	σ_w^2	σ_{rf}^2	σ_f^2	σ_e^2			
5-year survival	...	...	18.40	189.73	0.33	...	0.35
5-year height	1.880	0.218	.065	...	.45	0.12	.40
8-year height	12.47	2.02	2.22	...	.17	.53	1.27

1/ In the absence of a satisfactory formula for the standard error of the heritability, the ratio $\frac{\text{S.E. } (\sigma_f^2)}{\sigma_f^2}$ is used. If this ratio is greater than 0.50, reliability of the heritability value is low.

Table 2.--Correlations of progeny heights with parental diameters and heights before and after environment and age adjustments

Adjustments	Parental diameters	Parental heights
None	−0.28 (significant)	−0.04
Age	+ .02	+ .24 (significant)
Environment (via comparison trees)	− .06	+ .12
Age and environment	− .02	+ .17 (significant)

by subtracting the mean for trees on a particular site from the mean of the selected tree. The difference was entered in correlation computations. When both adjustments were applied, the age adjustments were applied first.

The highest positive parent-progeny correlation was r = 0.24 for parental annual height growth and mean family height (table 2). This indicates that the age adjustment alone was best. It is thus advisable to convert parental total height to annual height growth when calculating parent-progeny regressions. Using the r value of 0.24 in the formula

$$h^2 = 2b \frac{\sigma_x}{\sigma_y} = 2r$$

the heritability is 0.48 ± 0.21. The standard error was calculated from

$$S.E._{h^2} = \frac{2\ \sigma_x}{\sigma_y} \sqrt{\frac{1}{N-2} \left(\frac{\sigma_y^2}{\sigma_x^2} - b^2 \right)}$$

where N is number of pairs (adapted from Falconer 1960).

While mean annual height growth of parent is useful in selection, other measures such as the periodic annual height growth (Squillace et al. 1967) should be tested in the future.

The failure of comparison trees to increase parent-progeny correlations was disappointing (table 2). Perhaps peculiarities of site and the relative lack of competition among these open-grown longleaf pines made the technique ineffective. The failure suggests a need for reassessment of the use of comparison trees in selection.

Likewise, the negative correlation between diameter of parents and height of progeny was surprising. Parental diameter was not a helpful guide in selection. Since the traits in the parent generation were measured on mature trees, while in the progeny generation they were measured on young trees, an increase in these correlations can be expected in time. Therefore, the heritability of some characters estimated from parent-progeny correlations can be expected to increase as the progeny grow older. Whether this increase will be economically significant is not known.

Selection and gain.--When the best 25 percent of the parents were selected on the basis of annual height increment, percentage gain in progeny height was estimated by:

$$\frac{ish^2}{2\bar{x}} \times 100$$

where $i = 1.27$ (selection intensity)
$s = .3422$ (phenotypic standard deviation of parents)
$h^2 = .48$ (based on parent-progeny regression)
$\bar{x} = 1.84$ ft./yr. (parental mean)

This computed gain was 6 percent.

Realized gain was 12 percent. It is diagrammed in figure 1, where progeny heights are arrayed within parent tree height/age quartile classes. The mean heights of the progeny from parental quartile classes have the ratio 100:94:81:84. The corresponding ratio of the parents was 100:85:74:62. These results contrast with those of Rohmeder (1961) who stated (translation) that, "The fact that the expected ratio has not been found in any of the cases with various growth conditions and at various ages of progenies has meant disappointment for the plant breeders." He concluded that parental selection had little value, but in our investigation progenies from phenotypically selected parents were on the average 12 percent taller than the population average.

Considerable additional gain appeared to be possible from progeny-test selection. Selection of the 25 percent of the families with best mean plot heights results in 35 percent gain--an increase of 23 percent over parental selection. Because plot heritability was near 1.0 at 8 years (table 1), it is reasonable to expect that much of this gain would be genetic. Thus, it appears that at this intensity of selection, progeny testing was almost three times as effective as individual-tree selection for height growth in longleaf pine.

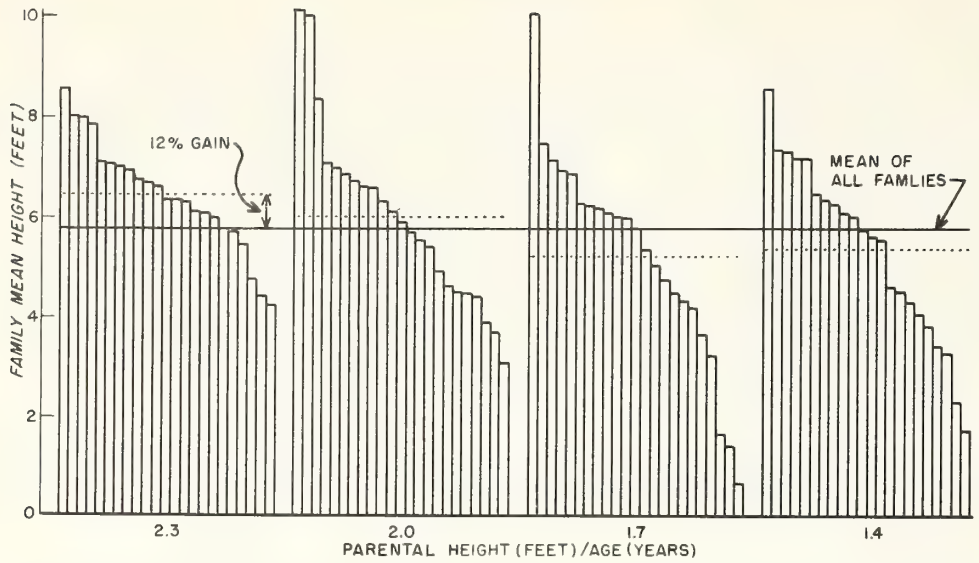

Figure 1.--Mean 8-year heights of families, by height/age quartile class of parent. Dotted line is mean of group. Each bar represents an average of 28 trees.

Another gain from progeny-test selection could be even more important. If the three best families are true genetic deviates, as seems likely from observation, their parents would be prime candidates in starting a new breeding program or seed orchard. Without progeny testing, the three most exceptional parents would have been lost to future breeding, because they were phenotypically unimpressive. Only about 30 percent of the parent trees could have been omitted from the progeny test with reasonable assurance of not missing these three parents.

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CLONE-SITE INTERACTION OF EASTERN COTTONWOOD

W. K. Randall and C. A. Mohn[1/]

Superior clones of eastern cottonwood (Populus deltoides Bartr.) are being sought for extensive plantations that are being established in the Lower Mississippi Valley. Site quality in this region varies from excellent on loamy soils to poor on heavy clay soils. Where there are large variations in site productivity, crop breeders have found important genotype-environment interactions. In the study reported here, clone-site interactions for cottonwood were sufficiently large to be considered in a breeding program.

MATERIALS AND METHODS

Seventy-nine cottonwood clones were planted on two sites near Greenville, Mississippi. Thirty-nine clones were selected from preliminary clonal tests, and 40 were randomly selected.[2/] All clones came from the natural population along the Mississippi River near Greenville, Mississippi.

One plantation was established on Commerce silt loam, one of the best cottonwood soils in the Mississippi Valley. The site index is 122 feet at age 30 (Broadfoot 1960). The other plantation was established on Sharkey clay, which is considered poor for cottonwood; the site index is 91 feet.

Both sites were cleared of vegetation in the summer and fall of 1964 and planted in February 1965. Maisenhelder's (1960) procedures were followed in planting and in subsequent cultivations. Standard 20-inch cuttings were treated with a systemic insecticide (44D Thimet)[3/] before planting. At each site four-ramet linear plots were arranged in a randomized complete block with five replications. Spacing was 10 by 10 feet. Height was measured to the nearest 1/10 foot after 1, 2, and 3 years, and diameter (d.b.h.), to the nearest 1/10 inch after 1, 2, 3, and 4 years. The 0.05 level was used in all tests of significance and in establishing the confidence limits.

Clone-site interactions were first examined by a combined analysis of variance using heights and diameters from the two sites. To further evaluate the interactions, the individual clone means at each site were ranked in descending order for both diameter and height. For each clone the absolute difference in rank positions between sites was used as an indicator of clone-site interaction.

1/ The authors are stationed at the Southern Hardwoods Laboratory, which is maintained at Stoneville, Mississippi, by the Southern Forest Experiment Station, USDA Forest Service, in cooperation with the Mississippi Agricultural Experiment Station and the Southern Hardwood Forest Research Group.

2/ Mohn, C. A., and Randall. W. K. Preliminary selection of eastern cottonwood clones. These proceedings.

3/ Mention of trade names is solely to identify material used and does not imply endorsement by the U.S. Department of Agriculture.

Initially, the eight tallest clones (10 percent) and the eight with largest diameters on each site were selected. Then, for each character, a population of eight clones was selected that had the highest mean rank for both sites combined.

RESULTS AND DISCUSSION

Height and diameter differed significantly among clones, among replications, and between sites for all ages. The clone-site interaction was significant for both height and diameter growth for all ages. The analyses of variance are summarized in table 1.

Table 1.--Combined analysis of variance for diameter and height

Source	Degrees of freedom	Mean squares				
		Diameter			Height	
		1 year	3 years	4 years	1 year	3 years
Site	1	17.9024*	213.9436*	321.8411*	648.4261*	14,674.7801*
Error I	8	.0572	.1142	.2987	2.0747	6.3847
Clones	78	.0720*	.2574*	.4263*	1.7687*	5.8851*
Site × clones	78	.0116*	.1123*	.1092*	.3503*	1.3605*
Error II	624	.0051	.0164	.0330	.1358	.8111

Mean diameter of all trees at age 4 was 5.7 inches (range 4.1 to 7.3) for the plantation on Commerce silt loam and 2.8 inches (range 2.0 to 3.9) for the plantation on Sharkey clay. The select clones had slightly larger diameters than the random clones.

Clone-site interaction was evaluated by comparing the change in rank of each clone between the two sites. For diameter growth, out of 79 positions, the mean clone movement between the two sites was 14 positions (range 0.5 to 42.0). The correlation coefficient (r) for diameter between the sites was 0.662.* Forty-five percent of the clones moved 0 to 10 positions, 24 percent 11 to 20, 23 percent 21 to 30, and 8 percent more than 31 places.

The mean change for height growth was 16 positions (range 0 to 51; r=0.619*). Forty-two percent of the clones moved 0 to 10 positions, 29 percent 11 to 20, 10 percent 21 to 30, and 19 percent more than 31 positions.

Table 2 gives the loss in mean diameter associated with planting on one site when selection was on another site or a combination of sites. The greatest loss in growth occurred when clones were selected on Sharkey clay and grown on Commerce silt loam. Table 3 summarizes the results of selection for height growth on single sites and a combination of two sites. There was very little difference in height growth of clones selected from sites other than the ones on which they were grown. As with diameter growth, the greatest loss of height growth occurred when selection was made on Sharkey clay for clones to be grown on Commerce silt loam. The diameter-growth responses are probably more important than those in height in a selection program because small changes in diameter greatly influence volume.

* Significant at the 0.05 level.

Table 2.--Results of selecting top 10 percent of clones from a single site and from mean performance on two sites for diameter growth

Site for selection	Planting site	Population mean	Mean difference	Increase of selected clones over population mean
		Inches	Inch	Percent
Sharkey	Sharkey	3.46	...	24
Commerce	do.	3.35	0.11±0.16	20
Combination	do.	3.38	.08± .15	21
Commerce	Commerce	6.81	...	20
Sharkey	do.	6.25	.55± .26	10
Combination	do.	6.68	.12± .22	17

Table 3.--Results of selecting top 10 percent of clones from a single site and from mean performance on two sites for height growth

Site for selection	Planting site	Population mean	Mean difference	Increase of selected clones over population mean
		Feet	Feet	Percent
Sharkey	Sharkey	21.45	...	16
Commerce	do.	20.82	0.62±0.74	12
Combination	do.	21.06	.38± .66	13
Commerce	Commerce	41.20	...	9
Sharkey	do.	39.98	1.22± .83	6
Combination	do.	41.14	.06± .79	9

Although the trees are still very young, the difference in diameter growth caused by clone-site interaction has practical significance. Because of this interaction, a particular genotype or group of genotypes may not be best for all environments. In crop breeding, two approaches have been used to reduce the effects of such interactions (Breese 1969). The first exploits the interactions by breeding and selecting for specific sites or soils. The second aims at development of a population that performs well over a broad spectrum of sites. The present data indicate that selection for specific sites may be more advisable than development of highly adaptable clones.

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VARIATIONS IN HEIGHT GROWTH AND CONELET SET IN TWO-YEAR-OLD F_2 SEEDLINGS OF LOBLOLLY PINES

James T. Greene 1/

Without selection, natural or artificial, there can be little genetic change of the forest. To determine if and how a particular characteristic is inherited, the tree improver must exert selection pressure on a specific characteristic. The ultimate goal is to incorporate the desired characteristics, whatever they may be, into a particular genetic strain. Breeding better forest trees, with attention to a particular characteristic, begins with a close look at what nature has already produced. Natural and planted populations often present the breeder with trees which show outstanding and desirable differences.

Variation in the vigor of progeny from individual trees is of great interest to workers engaged in forest tree improvement and forest genetics research. Trees that produce fast-growing offspring may provide the basis for a superior strain. Such trees may produce superior seed in sufficient volume for large scale nursery planting. They would also be valuable breeding stock for intra-and inter-specific hybridization.

The early production of strobili is essential in seed orchards and especially in a controlled-pollination program. In the establishment of breeding programs, distinct from vegetative propagation, it is apparent that any means which will hasten the onset of sexual maturity and increases the amount of seed produced will be of great importance. Most loblolly pine (Pinus taeda L.) trees begin to produce strobili at an age of about 8 to 10 years. By selection and controlled pollination, it should be possible to reduce "flowering" age. This will save valuable years in a genetics program as well as insure early seed production in a grafted or seedling seed orchard.

Description of Studies

Seed source studies of loblolly pines established in 1935 on the properties of the School of Forest Resources, University of Georgia offer a wide genetic base for the selection of phenotypes. These seed sources represent a single county from each of the following states: Alabama, Arkansas, Florida, Georgia, Louisiana, Maryland, Mississippi, North Carolina, South Carolina, Texas and Virginia. By intensive scouting in these plantations, individual trees that have twice the wood volume of the average tree in the same stand at the same age have been located. Furthermore, some of these loblolly pines are bearing seeds which produce seedlings that have mature cones at three and four years from seed.

1/ Associate Professor of Forest Genetics, School of Forest Resources, University of Georgia. This research was conducted in cooperation with the Georgia Forest Research Council and the College Experiment Station.

Approximately 800 trees were selected in these plantations for superior and inferior phenotypic characteristics. Some of the superior characteristics were: outstanding diameter and height growth, narrow crowns, straight stems, small limb size, seed production, long tracheid length, high specific gravity and apparent resistance to disease.

The inferior characteristics were: poor diameter and height growth, wide crowns, crooked and forked stems, large limbs, short tracheids, low specific gravity and susceptibility to disease. Some of these selected trees have been and are being crossed in all possible combinations to learn if and how the particular selected characteristics are inherited.

Progenies from some of these controlled crosses now offer excellent opportunities to make additional selections for desired characteristics. Approximately 100 possible combinations of crosses of loblolly pine trees are growing in the field in a randomized complete-block design with six replications. Each cross is represented in each block by one square plot of 25 seedlings spaced 10 X 10 feet.

This report will illustrate the effects of selection, controlled-pollinations and progeny testing of selected loblolly pine parents and their F_1 and F_2 progenies relative to their fecundity rate and height growth for the populations studied.

Results And Discussion

Flower Production

Greene (1966) reported on the seed yield and plantable seedlings from controlled and open-pollinated four and five-year-old seedlings of loblolly and shortleaf pines. These young "parents" were three and four years from seed when the pollinations were made. In these studies, seventy-seven per cent of the controlled-pollinations made in 1963 on four-year-old loblolly pines were successful. These crosses were F_2 and backcrosses.

The F_2 seedlings have been in the field for two years and represent 30 controlled loblolly pine progeny groups of approximately two-thousand seedlings from three and four-year-old parents. Nineteen per cent of the progeny groups were producing female strobili at one year in the field or two years from seed. Fourty-eight per cent of the progeny groups were producing female strobili at two-years in the field or three-years from seed. Crosses were made this year on the two-year-old trees.

Growth Rate

Some F_1 crosses are yielding approximately five cords per acre per year in seven years from seeds. At six years in the field, the best F_1 cross was averaging 8.2 inches approximately 4.5 feet above the ground, 32.0 feet in height and was producing approximately 30.08 cords of wood per acre.

As one might suspect, the poorest specific cross was producing

considerably less than one cord per acre per year.

The best loblolly F_1 cross relative to height growth and yield also produced the fastest growing F_2 progeny todate. The mean of the best F_2 cross in two years was 9.1 feet and the tallest individual within the group was 12.2 feet (Table 1).

The range in average height growth among the two-year-old F_2 progeny groups was from 6.6 feet to 9.1 feet for a difference of 2.5 feet. This is a 38 per cent increase in height growth between the poorest and the best F_2 cross.

The average height growth for Coastal Plain and Piedmont loblolly pines is approximately 1.50 feet per year (Zobel 1968). On this basis, the poorest F_2 progeny are making 100 per cent better height growth than the average Piedmont and Coastal Plain loblolly pines at two years. The best F_2 progeny is growing 200 per cent better than the average Piedmont and Coastal Plain loblolly pines at two years (Table 1).

The F_2 generation, in our studies are characterized by a high degree of diversity. This is evident by variations of height growth within and among the progeny groups (Table 1). Variations in height growth within progeny groups varied as much as 7.7 feet with a range of 4.0 feet to 11.7 feet.

Variations of height growth among the individual trees that make up the entire progeny groups varied from a low of 4.2 feet to a high of 12.2 feet, a difference of 8.0 feet in two years.

These data clearly illustrate the importance of selection, controlled-pollination and progeny testing for height growth and early "flower" production. It is within and among these known progeny groups that selection pressure can best be exerted on height growth and "flower" production for the next generation. The tree improver can either select the individuals within the 4.0 feet class or the individuals that are within the 12.0 feet class for his parental stock and future generations. This possibility has great promise in programs of tree improvement and especially from the practical aspect of producing commercial quantities of improved seed from "Seedling" orchards.

Table 1. Height Growth in Feet of Two-Year-Old F_2 Seedlings of Loblolly Pines From 3-and 4-Year-Old Parents

Cross	Average Height	Height Range Within Progeny Groups	Variations Within Progeny Groups
8	6.6	4.2 - 8.9	4.7
1	6.8	5.9 - 8.4	2.5
3	6.8	4.3 - 8.4	4.1
20	6.9	5.2 - 9.3	4.1
9	7.0	4.9 - 8.4	3.5
2	7.4	3.4 - 9.3	5.9
18	7.4	4.9 - 9.6	5.3
30	7.6	4.8 - 11.4	6.6
6	7.8	5.7 - 10.1	4.4
21	7.9	4.6 - 10.5	5.9
26	7.9	4.0 - 11.7	7.7
11	7.9	3.6 - 9.6	6.0
12	8.0	5.2 - 10.1	4.9
29	8.0	4.7 - 10.0	5.3
27	8.0	5.6 - 10.1	4.5
25	8.0	5.4 - 10.0	4.6
7	8.0	5.6 - 9.4	3.8
4	8.1	5.2 - 10.0	4.8
10	8.1	6.9 - 9.5	2.6
14	8.1	7.1 - 9.3	2.2
15	8.1	5.7 - 9.9	4.2
16	8.1	3.4 - 10.9	7.5
23	8.3	6.2 - 10.7	4.5
5	8.6	6.4 - 10.7	4.3
19	8.6	7.5 - 10.1	2.6
17	8.8	6.4 - 10.6	4.2
22	8.9	5.9 - 11.9	6.0
28	9.0	6.7 - 11.5	4.8
13	9.0	7.1 - 11.4	4.3
24	9.1	7.1 - 12.2	5.1

Summary

A study of variation, selection, controlled-pollinations and progeny testing of selected parents and their F_1 and F_2 progenies relative to height growth and strobili production was conducted with the following results.

1. These data prove that F_2 seedlings of loblolly pines can be successfully grown in five to six years from seed involving three-and four-year-old parents for the populations studied.

2. Nineteen per cent of the F_2 loblolly pine progeny groups produced female strobili at one year in the field or two years from seed.

3. Forty-eight per cent of the progeny groups produced female strobili at two years in the field or three years from seed.

4. Some F_1 crosses of loblolly pines yielded approximately five cords per acre per year in seven-years from seeds.

5. The best loblolly F_1 cross relative to height growth and yield also produced the fastest growing F_2 progeny todate. The mean of this cross in two-years was 9.1 feet and the tallest individual within the cross was 12.2 feet.

6. The range in average height growth among the two-year-old F_2 progeny groups was from 6.6 feet to 9.1 feet for a difference of 2.5 feet. This is a 38 per cent increase in height growth between the poorest and the best F_2 cross.

7. The average growth rate in height for Coastal Plain and Piedmont loblolly pines is approximately 1.50 feet per year. On this basis, the poorest F_2 progeny are making 100 per cent better height growth than the average Piedmont and Coastal Plain loblolly pines at two years, whereas the best F_2 progeny are making 200 per cent better height growth.

8. Data indicate that age of "flowering", fecundity rate, height growth and yield in loblolly pines for the populations studied can be altered by selection, controlled-crossing and progeny testing.

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TESTING SLASH PINE FOR RUST RESISTANCE IN ARTIFICIAL AND NATURAL CONDITIONS

Ronald J. Dinus[1/]

Field tests to locate southern pines resistant to fusiform rust (Cronartium fusiforme Hedgc. & Hunt ex Cumm.) are costly, time-consuming, and often unreliable (Henry and Jewell 1963; Kinloch and Kelman 1965; LaFarge and Kraus 1967). Hence, Jewell (1960) devised an inoculation technique in which telia-bearing oak leaves are suspended over pine seedlings in the cotyledon stage grown under controlled conditions of temperature and moisture. The technique was subsequently modified (Jewell and Mallett 1964, 1967) to increase its capacity and efficiency.

This and related approaches (Arnold and Goddard 1966; Davis and Goggans 1968; Driver et al. 1966) attempt to provide favorable conditions for infection and uniform, abundant supplies of inoculum. The test may be too severe, however, since selections having slight but useful resistance might be eliminated. Since resistance to some diseases varies with age (Patton 1961), tests on juvenile material could be unrealistic. Furthermore, testing during a single life stage with more or less local inoculum could result in selection for specialized rather than generalized resistance (Smith 1968).

This paper describes the relationship between infection rates under artificial conditions and those observed in field plantings at a number of locations and after several years of exposure. Results indicate that response to artificial inoculation is a reliable index of field performance; both types of tests, however, are valuable in breeding for rust resistance.

MATERIALS AND METHODS

Six slash pines (Pinus elliottii Engelm.) were selected in Harrison County, Mississippi, for use in artificial and field inoculation tests (Jewell and Mallett 1967). Three were rust-free (8-7, 11-6, and 18-27), and three were infected (18-40, 18-41, and 18-62). The natural stands involved were about 75 percent infected. Open-pollinated seed was collected over a period of several years from each of the six selections.

Dr. F. F. Jewell[2/] artificially inoculated open-pollinated progenies in identical randomized block designs in 1963 and 1964. Each family was represented by two rows of 18 trees in each of five blocks. Proportions of plants infected per row were determined 9 months after inoculation. Results of one of the individual experiments were reported previously (Jewell and Mallett 1964). For presentation here, the original data were reanalyzed as separate tests and as a single experiment combining both years. The proportion of plants infected was

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1/ The author is stationed at the Institute of Forest Genetics, Southern Forest Experiment Station, USDA Forest Service, Gulfport, Mississippi.

2/ Currently Associate Professor of Forest Pathology, Louisiana Polytechnic Institute, Ruston, Louisiana.

transformed to degrees arc sine and subjected to analysis of variance for the randomized block design with more than one observation per experimental unit (Steel and Torrie 1960). Family means were compared by multiple range tests at the 0.01 level.

Field tests of open-pollinated progenies from the same selections were established by Jewell in 1963 at Gulfport, Mississippi, and in 1964 on Crown Zellerbach Corporation land near Bogalusa, Louisiana. The Gulfport planting contains progenies from all six selections in a randomized block design. Each family is represented by two rows of 15 trees in each of seven blocks. The Bogalusa planting consists of five blocks each containing two rows of 15 trees; five families are represented.

Survival, total height, and rust infection were measured annually. Rust infection was observed in terms of three indices: number of stem infections per plant, total number of infections per plant, and proportion of plants infected per row. The proportion infected in the latest year was also analyzed after plants previously infected but currently rust-free had been deducted. Percent of survival and the proportion infected were transformed to degrees arc sine. Row means for the six variables were subjected to analysis of variance for the randomized block design with more than one observation per experimental unit. A combined analysis of both locations was not attempted as the effect would have been confounded with different planting dates. Family means were compared by multiple range tests at the 0.01 level. In addition, simple correlations were calculated to determine if survival and growth were associated with infection and which index best measured infection.

RESULTS

Artificial inoculation.--Variation among families was significant in both 1963 and 1964. In both years, the proportion of diseased plants from one rust-free and the three infected selections was greater than from the remaining rust-free selections (fig. 1). The combined analysis confirmed the significance of variation among families. However, both the year × family interaction and differences between years were nonsignificant.

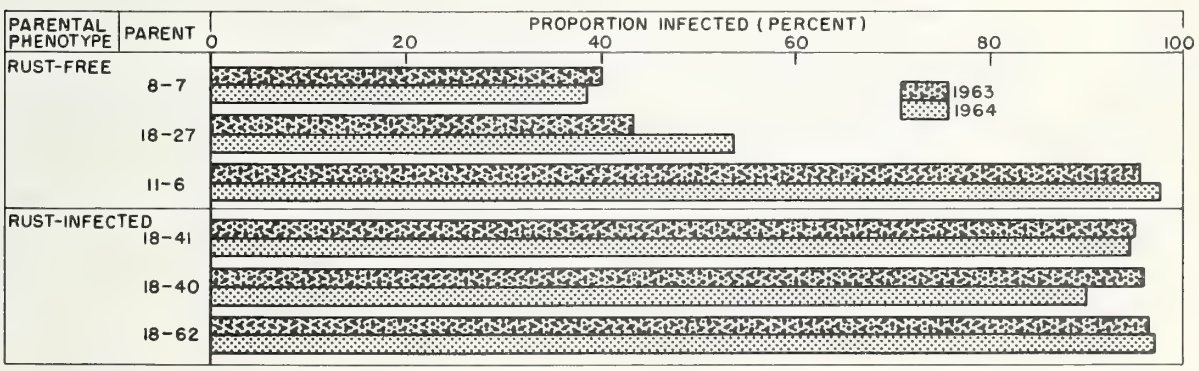

Figure 1.--Artificial inoculation of open-pollinated slash pine seedlings, 1963 and 1964.

Field survival.--Survival at the latest measurement varied significantly among families at Bogalusa, but not at Gulfport (table 1). Mortality was heaviest shortly after planting. Simple correlations between survival and the three indices of infection were nonsignificant.

Table 1.--Mean percentage survival of open-pollinated slash pine progenies

Parent	Bogalusa, year 4	Gulfport, year 5
18-27	1/ 86.6	67.7
8- 7	86.2	88.0
18-40	79.7	83.5
18-41	...	82.5
11- 6	57.3	85.1
18-62	54.1	84.3

1/ Values connected by the same vertical lines do not differ significantly at the 0.01 level according to Duncan's test.

Total height.--Differences among families in total height became apparent after 3 years in the field. After 4 years at Bogalusa, variation among families was significant. A rust-free selection, 11-6, produced the slowest growing progeny. Their mean height was significantly less than that of the tallest family (fig. 2). Differences among families after 5 years at Gulfport were not significant. Regardless of age or location, progenies of both rust-free and infected selections were among the fastest growing lines. Simple correlations between infection rates and height or average annual height increment during the first 3 years were nonsignificant.

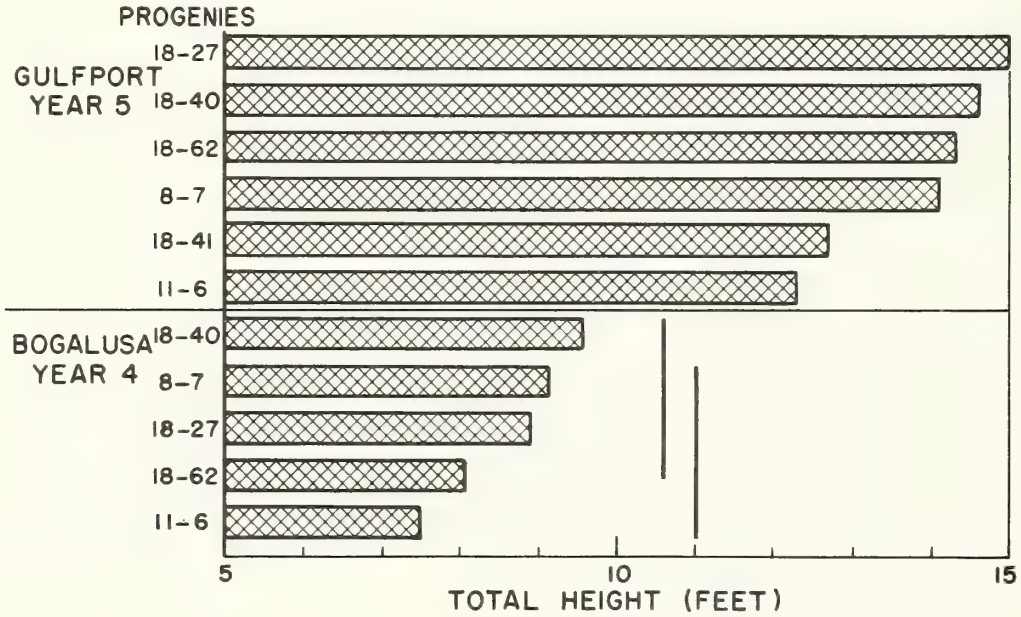

Figure 2.--Mean height of open-pollinated slash pine progenies at two locations. Values connected by the same vertical line do not differ significantly at the 0.01 level according to Duncan's test.

Stem infections.--Stem infections appeared as early as 1 year after planting at both locations. Since then, the number per plant has increased steadily and significant differences among families were noted after 2 years of exposure. Although few changes in family ranking have occurred since, considerable variability was encountered within families. For example, the coefficient of variation at Gulfport ranged from 108 percent during the second year to 65 percent in the fifth year. This high error rate indicates that distinguishing between resistant and susceptible lines required at least 4 to 5 years of exposure. By then, progenies of 18-40 and 18-62 had more stem infections than those of any other selection (table 2). In addition, progeny of 8-7 at Gulfport had fewer stem infections. Simple correlations between numbers of stem infections and other infection indices were significant at the 0.01 level.

Table 2.--Mean numbers of infections per plant among open-pollinated slash pine progenies

Location	Family	Number of infections per plant	
		Stem	Total
Gulfport, year 5	18-62	0.65 [1/]	1.71
	18-40	.60	1.72
	18-27	.36	.87
	11- 6	.32	.62
	18-41	.31	.78
	8- 7	.02	.04
Bogalusa, year 4	18-62	.42	1.46
	18-40	.40	1.90
	18-27	.20	1.19
	11- 6	.14	.52
	8- 7	.04	.05

1/ Values connected by the same vertical lines do not differ significantly at the 0.01 level according to Duncan's test.

Total infections.--Increases in the total number of infections per plant occurred each year and were consistently larger for progenies of rust-infected selections. However, the frequency of new infections fluctuated widely from year to year and considerable variability existed within families. Coefficients of variation decreased with years of exposure, but were never less than 41 percent. However, differences among families have been significant since the second year and family ranking has changed only slightly since the third year. At Gulfport after 5 years of exposure, progenies of 18-40 and 18-62 had more infections than those of all other selections (table 2). Progenies of 18-41, 18-27, and 11-6 had fewer infections than these, but more than those of 8-7. A similar pattern emerged at Bogalusa after 4 years (table 2). Progenies of 8-7 and 11-6 had fewer infections than any others. Simple correlations between total infections and the proportion infected were significant at the 0.01 level.

Proportion infected.--Annual increases in numbers of newly infected plants varied between years and locations (fig. 3). However, family rankings have been similar at both locations since the first infections were noted. Initially, variation within families was large, but coefficients of variation have been less than 30 percent since the third year. Consequently, differences which were evident among families within 2 years of planting have become more definite. At last measurement, variation among families was significant. Regardless of location, fewer progeny of 8-7 were infected than of any other selection (fig. 3). On the other hand, progenies of 18-62 and 18-40 were by far the most frequently infected. Progenies of one rust-infected (18-41) and two rust-free selections (18-27 and 11-6) differed significantly from both the best and worst families and exhibited intermediate levels of infection at both locations. When plants previously infected but rust-free at the last measurement were deducted from the analyses, results were essentially the same (fig. 3).

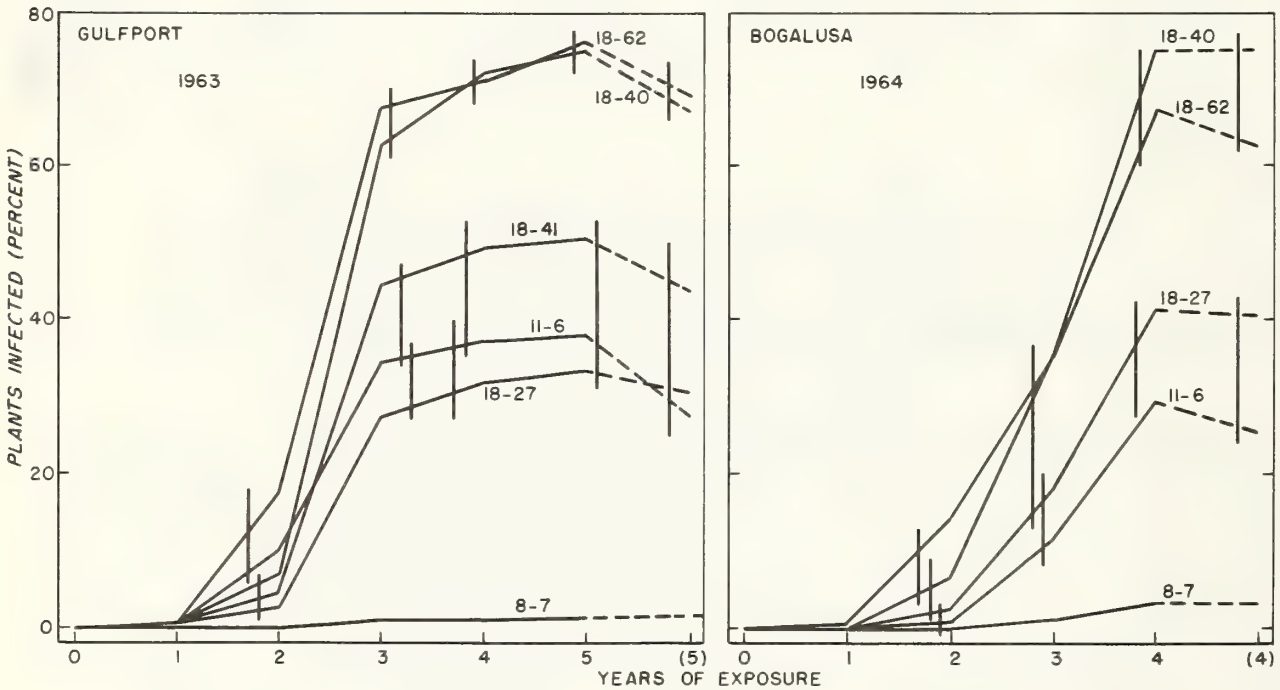

Figure 3.--Mean proportions of plants infected (percent) among open-pollinated slash pine progenies at two locations. Values connected by the same vertical line do not differ significantly at the 0.01 level according to Duncan's test. Years in parentheses denote results after plants previously infected but now healthy were deducted.

DISCUSSION AND CONCLUSIONS

The three indices of infection gave the six families similar ratings and were significantly correlated. The proportion infected seemed the most reliable index. A curvilinear relation existed between total infections and the proportion of plants infected similar to that found for loblolly pine, (Pinus taeda L.), (Kinloch 1968). That is, infections per plant tended to increase faster than the number of infected plants. This relation suggests that infections per plant may be more sensitive in heavily infected areas or when families concerned have only slight resistance. However, this trend did not appear until the fourth and fifth years. In addition, large error terms were encountered in analyses based on stem and total infections. Results from the proportion of plants infected paralleled those obtained after adjustment for plants previously infected but not showing infection at the last measurement. This agreement demonstrates that a single scoring 4 or 5 years after planting can provide a realistic estimate of field performance, at least in controlled, well-replicated plantations.

Combined analysis of the two artificial inoculation tests demonstrated that the technique yields consistent results. Progenies of 8-7 and 18-27 resisted artificial inoculation and performed better than average in the field (fig. 4). While not best in the field, progeny of 18-27 were significantly more resistant than the worst families. Since both these selections demonstrated heritable resistance in both types of test, it appears that they can be used safely in breeding programs as suggested by Jewell and Mallett (1967). This conclusion seems especially sound as these were open-pollinated progeny from a rust-free selection in a stand that was 75 percent infected. Even better field performance can be expected from crossing individuals thus identified. For example, progeny from the cross between 8-7 and 18-27 or its reciprocal averaged only 10 percent infection in a series of artificial inoculations (Jewell and Mallett 1967). Consequently, selection and breeding on the basis of artificial inoculation results should yield rapid improvement. Judgments based on artificial inoculation results err only on the safe side. Of the progenies resistant to artificial inoculation, none were found susceptible in the field (fig. 4) even after several years of exposure at two locations. While some potentially useful selections may be overlooked, susceptible ones will not go undetected.

According to the nursery test (fig. 1), the infected selections, 18-62, 18-40, and 18-41, are undesirable for inclusion in breeding programs. The presence of 18-62 and 18-40 in the upper right quadrant of figure 4 supports this conclusion and further demonstrates the close agreement between artificial and field testing. While 18-41 seems undesirable at first glance, its intermediate field performance (fig. 3) makes outright rejection questionable. Assuming that resistance is controlled by additive genes (Kinloch 1968) or at least not by a single dominant gene (Jewell and Mallett 1967), this intermediacy suggests that 18-41 possesses some genes for resistance. That is, it has a larger complement than 18-62 or 18-40, but smaller than 8-7. Data from previous artificial inoculations (Jewell and Mallett 1967) support this inference. Progeny from the cross between 8-7 and 18-62 were 44 percent infected. Crossing 8-7 with 18-41, however, produced progeny which were only 23 percent infected.

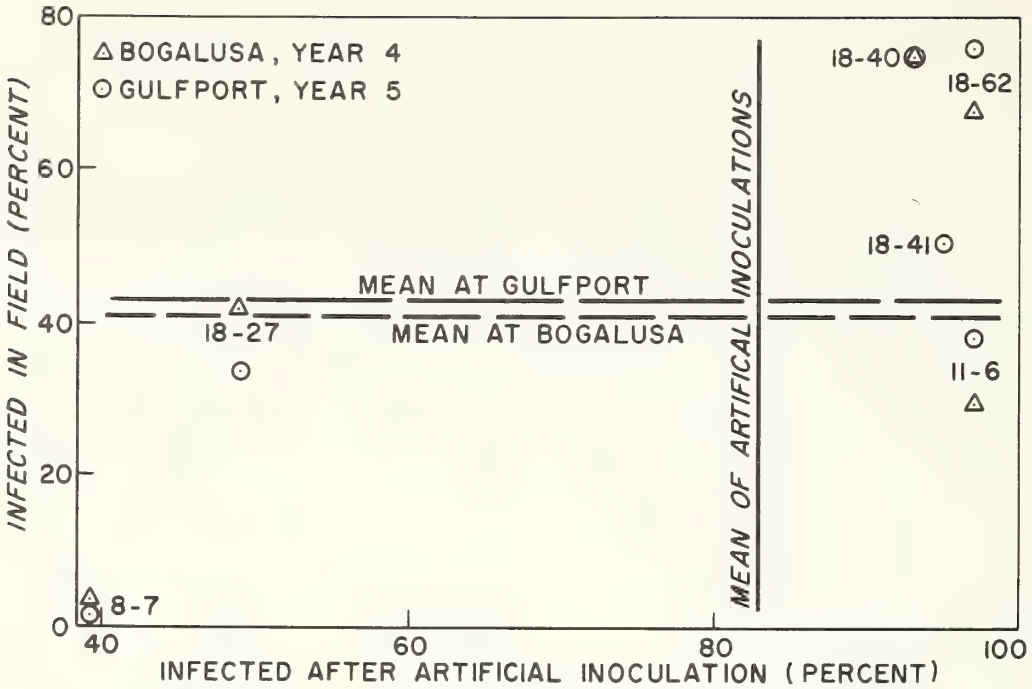

Figure 4.--Relationship between the results of artificial and natural inoculations of open-pollinated slash pine progenies.

Relying on the artificial testing of open-pollinated progenies would have eliminated 18-41. Thus, such tests may be too severe, but they identify the most resistant selections several years before field tests would. The accumulated data suggest a means of circumventing this weakness. For example, partially resistant and potentially useful selections such as 18-41 can be identified by screening control-pollinated progenies or at least progenies of crosses between candidates and specific tester parents like 8-7. Partially resistant selections thus could be located among individuals more desirable from other aspects. Parents with appropriate degrees of resistance could be identified to reforest areas of varying rust hazard.

The rust-free selection, 11-6, performed better in the field than might have been expected on the basis of artificial inoculation alone (fig. 4). Its performance in other Gulfport plantings has also exceeded expectation. This deviation from agreement infers that 11-6, like 18-41, either possesses fewer genes for resistance than 8-7 or has a different form of resistance. Available evidence favors the latter premise. First, 11-6 performed quite differently in two types of test. Second, artificial inoculation of progeny from crosses between 11-6 and 8-7 resulted in 53 percent infection (Jewell and Mallett 1967). Progeny from its cross to 18-62 were 95 percent infected. Thus, 11-6 did not combine as well with 8-7 as 18-41 and was highly susceptible in combination with a susceptible selection.

The field resistance of 11-6 may be dependent upon age or interaction with the environment for its expression. An increase in resistance to blister rust, Cronartium ribicola J. C. Fisch., with age was observed by Patton (1961). The progeny of 11-6 tended to be the slowest growing of those tested (fig. 2).

Hence, its resistance may be an indirect result of mediocre growth. Low vigor and resistance are often related in cases of obligate parasitism (Heimburger 1962; Illy 1966). Whatever the underlying causes, the departure of 11-6 from agreement demonstrates that joint artificial and field tests can identify selections having different forms of resistance. Thus, acceptable genotypes can be combined purposefully, rather than haphazardly, for greater progress.

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INBREEDING AS A MEANS OF GENETIC IMPROVEMENT OF LOBLOLLY PINE

E. C. Franklin[1/]

Traditionally, there has been much speculation and little basic scientific understanding about the potential uses of inbreeding as a means of improving forest trees. Many of us at some time have indulged in a starry-eyed vision of a four-way, double-cross, super-hybrid loblolly pine (or substitute your own favorite species). Recent data from a study in loblolly pine indicate that inbreeding has rather limited potential as a direct means of tree improvement for this species. The study involved comparisons of 75 self- and 75 cross-pollinated families in two replicated greenhouse experiments (Franklin 1968). Additional data were provided from subsequent field plantings, established and maintained in cooperation with North Carolina State University and Albemarle Paper Company.[2/]

EFFECTS OF INBREEDING

Lower Yields of Seedlings

Seedling yields per cone harvested from self- and cross-pollinations on the same trees have been compared (table 1). Number of 6-month-old seedlings per cone harvested was only one-seventh as great from selfs as from crosses. Thus, to obtain equivalent seedling yields, seven times more selfed cones as crossed cones are required. When the seedlings are outplanted and grow older, there will continue to be more mortality among selfs than crosses, particularly in cases of environmental stress. Comparative costs of producing equivalent numbers of inbred and crossbred seedlings must be a major consideration in evaluating inbreeding as a method of tree improvement.

[1/] Plant Geneticist, Southeastern Forest Experiment Station, Forest Service, U. S. D. A., Naval Stores and Timber Production Laboratory, Olustee, Florida.

[2/] Cooperators: N. C. State-Industry Cooperative Tree Improvement and Hardwood Research Programs; Albemarle Paper Company, Roanoke Rapids Division, Roanoke Rapids, N. C.

Table 1.--Comparison of seed and seedling yields after self- and cross-pollination

	Self	Cross
Total seed per cone	32.7	36.7
Minus empty seed per cone	-28.0	-9.5
Filled seed per cone	4.7	27.2
Minus nongerminating seed	-1.2	-4.0
Germinable seed per cone	3.5	23.2
Minus mortality at six weeks	-0.2	-0.5
Number of living seedlings per cone at six weeks of age	3.3	22.7
Cones required for equivalent seedling yields at six weeks of age	7	1

Pregerminative Selection

The large number of empty seeds following selfing (table 1) indicates that self-fertilized embryos failed to mature in the majority of ovules. Self-pollination yielded only 11 percent viable seed compared to 63 percent following cross-pollination. The stronger natural selection pressure against self-fertilized zygotes eliminates a substantial proportion of the selfbred population before the breeder even collects seed. Natural selection is operative on a trait of no economic importance; namely, pregerminative survival capacity under selfing. The relationships of this trait to economically important traits are not known. Therefore, with selfing the breeder is forced to accept a highly selected population, without knowing how the preselection has biased his chances for genetic gain through further selection.

Imbalance of Experimental Designs

Performance was consistently poorer after selfing than after crossing (table 2). Selfed families had lower germination and lower survival than comparable crossed families. Furthermore, variation in germination and mortality was strongly associated with individual parent tree responses to selfing. Regarding experimental design, this meant that often all the trees from several family plots were lost, instead of a few trees from many different family plots being lost. Consequently, missing plots were much more numerous among families after selfing than after crossing. In one field planting, 675 selfbred and 675 crossbred 1-0 seedlings were planted in three-tree row plots. One year later 143, crossbred seedlings had died, resulting in one missing plot; but, 232 selfbred seedlings had died, resulting in 17 missing plots. Analytical problems caused by missing plots increase the costs and decrease the efficiency of statistical analyses.

Table 2.--Family means, coefficients of variation and correlation coefficients after self- and cross-pollination, for seed and seedling traits

Trait	Means		Coefficients of variation		Correlation[a] coefficients
	Self	Cross	Self	Cross	Self x Cross
Filled seed (percent)	21.7	76.5	60.8	20.2	0.02
Seed weight (mg)	22.7	23.3	27.4	27.9	.69
Germination (percent)	73.1	84.9	2.3	0.8	.29
Germination rate (days to germinate)	6.53	6.31	16.1	16.7	.57
Hypocotyl height (mm)	37.7	40.7	15.8	9.5	.63
6-month height (cm)	23.8	27.3	12.7	7.2	.84
Survival at 6 weeks (percent)	97.1	98.6	5.0	2.4	.15
2-year height[b] (feet)	1.07	1.23	23.3	21.7	.48
Survival at 2 years[b] (percent)	65.6	78.8	42.5	31.3	.27

[a]First seven correlations estimated with 51 degrees of freedom; the last two estimated with 44 degrees of freedom.

[b]One year after outplanting as 1-0 stock.

Another disadvantage of selfed families was that they generally had higher coefficients of variation than crossed families (table 2). Compared to crossbreds, inbreds seemed to be hypersensitive to environmental stresses. This is also an important consideration in experimental design, because greater variation among experimental units necessitates larger experiments to achieve comparable precision for estimates, other factors being equal.

The use of inbred material presents some difficult and potentially expensive problems in seedling production, artificial selection, and experimental design. The question is whether the benefits derived from inbred material justify its use in preference to crossbred material despite the disadvantages discussed above.

USES OF INBRED MATERIAL

Production of Base Populations for Selection

The success of corn breeders using the inbreeding-outcrossing hybrid method has always impressed tree breeders. As early as 1929, Kolesnikov suggested that pure line breeding would be a good approach for forest tree improvement. Even today, as the corn breeders are turning more and more to outcrossing, recurrent selection methods (Duclos and Crane 1968), some tree breeders still advocate inbreeding programs for tree improvement (Righter 1960; Dieckert 1964b; Pawsey 1964; Keiding 1968). "On the basis of present information, hybridization programs were initiated in maize before there was genetic need for such programs. . . . In the 1920's, when the current hybridization programs were initiated, selection was thought to be ineffective. Current information indicates that selection, properly performed, is still an efficient tool. The results with maize, therefore, do not constitute an adequate justification for a hybridization program with other crops" (Sprague 1966, page 336).

The biological and economic inferences most strongly supported by the results with controlled inbreeding in loblolly pine indicate that crossbreeding should be favored over inbreeding in production of base populations for selection. The same conclusion has been reported for slash pine (Snyder 1968). Costs in time and capital outlay would necessarily be greater and gains would be more slowly achieved with inbreeding than with crossbreeding programs. Sacrifices in long-term genetic flexibility are inherent in an inbreeding-outcrossing hybrid method because, once the hybrid is obtained, the breeder must start over again each time to produce a new variety for a newly discovered need. This lack of flexibility is particularly disadvantageous with a plant such as loblolly pine because generation intervals are so long. Crossbreeding programs, such as reciprocal recurrent selection, offer long term flexibility in selection of several strains simultaneously and show promise of exceeding the gains possible with inbreeding (Penny 1968). To really profit from the experience of corn breeders, outbreeding methods should be used in loblolly pine. By so doing, we may be able to avoid the tree breeders' version of--

The Shattered Dream of a Corn Breeder[3/]

Selfed a hundred corn plants,
Put each in a cross;
Selfing without testing,
Means a heavy loss.

Looked around the country,
Found a fertile field,
Used a ten-ten lattice
To find out how they'd yield.

Analyzed the variance,
Wanted just the best;
Planted only thirty,
Threw away the rest.

Thirty, good in hybrids,
That would be a plenty;
Heavy rains, and lodging;
Then there were twenty.

Still had twenty inbreds
Looking mighty keen;
Hot, humid weather;
Smut left thirteen.

Lucky thirteen inbreds,
Glad to be alive;
Wilt, blight, and aphids;
Then there were five.

So passed the summer,
Full of sweat and tears;
Came then the harvest--
Four had rotted ears.

One sturdy inbred,
All, all alone;
It has no sex appeal
Can't find a home.

Frederick D. Richey, Knoxville, Tenn.

[3/] Briggs, F. M., and Knowles, P. L. Introduction to plant breeding. Pp. 237-238. New York: Reinhold Publishing Corp. 1967.

Progeny Testing

In loblolly pine there are moderately high correlations between self-combining ability and cross- (i.e., general) combining ability in most traits, particularly height growth (table 2). Similar correlations for several traits have been reported in other species (Dieckert 1964a; Fowler 1965; Bingham 1966; Nikles 1966; Snyder 1968). These results have led to the suggestion that selfing might be used as a method of progeny testing. With this method, candidate trees would be ranked according to the performance of their offspring resulting from self-fertilization. The assumption is that ranking based on selfing would be similar to the ranking based on some other form of progeny testing, such as using a pollen mix or a tester system.

In progeny testing, the ideal is to have the progeny performances indicate perfectly the breeding value of the tested parent trees. A disadvantage of crossbreeding systems is that the breeder must arbitrarily choose a limited number of tester trees or sources of pollen for mixes. He must then assume that the sample will reliably represent the average performance of parent trees under seed orchard or other seed production conditions. Progeny testing using selfbred progeny would eliminate the need of an arbitrary choice of test pollen and would thereby standardize the testing procedure to some extent. An experimental comparison of crossing and selfing as progeny testing methods was obtained from height data from 51 selfbred and crossbred families (Franklin 1968). There was a fairly strong overall correlation between the ranked array of families produced by crossing with a five-tree pollen mix, and the corresponding families produced by selfing (figure 1). Nevertheless, the best 10 parent trees, chosen on the basis of self-combining ability, included only six of the parent trees indicated to be best on the basis of cross-combining ability.

Although it may be possible to use inbred offspring for progeny testing, the overwhelming evidence is that alternative methods will be more efficient. For example, some candidate trees could never be progeny tested using selfed offspring because they would never yield viable seed when selfed. In addition to requiring seven times more cones for equivalent yields of 6-month-old seedlings (table 1), larger coefficients of variation (table 2) will necessitate larger experiments to achieve equivalent precision on estimates. Added to these problems is the apparent hypersensitivity of selfs to environmental stress which increases mortality.

Progeny tests based on self-pollinated families will give essentially the same information as tests with corresponding cross-pollinated families, i.e., general combining abilities. Therefore, use of selfs for progeny testing has no important advantage, but does have some significant disadvantages, and should not be considered as a general method of progeny testing loblolly pine.

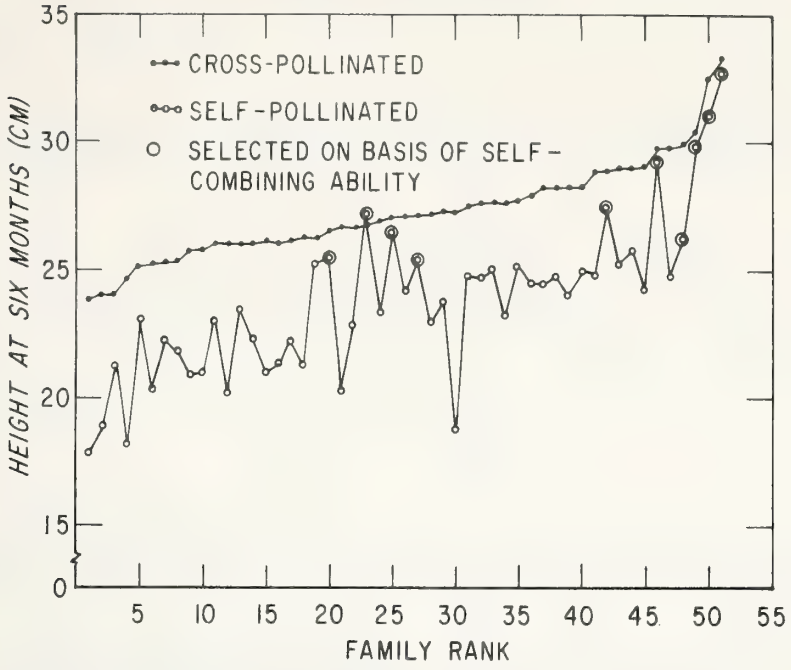

Figure 1.--Correlation between family mean heights based on self- and cross-pollinations of 51 parent trees (cross pollen was a five-tree mix).

Estimation of Genetic Components of Variance

Selection indices will be powerful tools for tree improvement in the near future. To obtain efficient indices, precise estimates of genetic components of variance and covariance are needed. Estimation of these compoents requires large amounts of control-pollinated material suitable for use in relatively refined statistical designs. Results with controlled inbreeding in loblolly pine prove it to be an inefficient method of obtaining large quantities of such material. Adequate mating designs based entirely on outcrossing are available for variance component estimation (Stonecypher 1966). Therefore, it is neither necessary nor efficient to try to use inbreeding for estimation of genetic components of variance in loblolly pine, except in the rare instance when the desired information can be obtained in no other way.

SUMMARY

The utility of inbreeding as a means of tree improvement has long been a topic for debate. Inbreeding has been suggested as a method of progeny testing, as a method of producing base populations from which to make se-

lections, and as a means of estimating components of genetic variance. Recent results for loblolly pine showed that seedling yields per cone harvested after selfing were only one-seventh as great as those after crossing. Seedling mortality also increased significantly as a result of selfing. Increased mortality after selfing poses difficult problems in experimental design and interpretation under the rather severe environmental conditions of forest testing. Consequently, inbred seedlings are more difficult and more expensive to produce and to use than are crossbred seedlings. With respect to tree improvement methods and procedures, information and materials obtained by inbreeding can usually be obtained at a much lower cost by crossbreeding. Therefore, the utility of inbreeding for genetic improvement of loblolly pine is quite limited.

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SESSION III

Geographic Variation

Moderator: Charles Webb

From left to right: G. A. Snow, O. O. Wells, R. E. Schoenike, Clark W. Lantz, Clayton Posey, Ralph A. Lewis, Gene Namkoong, Charles Webb, L.C. Saylor

RESULTS OF THE SOUTHWIDE PINE SEED SOURCE STUDY THROUGH 1968-69

O. O. Wells[1/]

The Southwide Pine Seed Source Study[2/] was undertaken in 1951 to determine the degree to which inherent geographic variation in longleaf pine (Pinus palustris Mill.), slash pine (P. elliottii Engelm. var. elliottii), loblolly pine (P. taeda L.), and shortleaf pine (P. echinata Mill.) is associated with geographic variation in climate and physiography. The information was intended for use in delimiting practical seed-collecting zones for these species.

The main features of the study are a randomized block design with four blocks in each planting, large plots, and relatively few seed sources but at least one planting in the vicinity of each seed source. The longleaf and shortleaf tests include a replication by year, since seed was collected in both 1951 and 1955 and plantings were established in 1952 and 1956. All of the loblolly and slash plantings were established in 1952-53 from seed collected in 1951.

The seed sources and plantings of longleaf, shortleaf, and loblolly are divided into series. The division was necessitated by the practical difficulty of planting trees from all seed sources of a species in all the areas judged necessary for an efficient test. Sources and plantings in each series were selected to test specific hypotheses. Thus, shortleaf Series 4 samples the north-south extremities of the species' range to test whether climatic effects associated with latitude are important determinants of geographic variation. Similarly, shortleaf Series 6 holds latitude nearly constant to determine the effect of

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1/ The author is stationed at the Institute of Forest Genetics, Southern Forest Experiment Station, USDA Forest Service, Gulfport, Mississippi.

2/ The Study is sponsored by the Southern Forest Tree Improvement Committee through its Subcommittee on Geographic Source of Seed. The members of this subcommittee are:

T. E. Bercaw, Crown Zellerbach Corporation (deceased)
Richard C. Fox, Clemson University
Berch W. Henry, Southern Forest Experiment Station
A. E. Squillace, Southeastern Forest Experiment Station
O. O. Wells, Southern Forest Experiment Station (Chairman)
Bruce Zobel, North Carolina State University

Messrs. Henry and Zobel have served on the subcommittee since the planning stages of the study, as did Mr. Bercaw. The original chairman and principal organizer of the study, P. C. Wakeley, retired from the Southern Forest Experiment Station in 1964.

Establishment, maintenance, and measurement of the plantings are by Federal, State, educational, and industrial cooperators who generously contribute their time and effort.

longitude. Within any one series all seed sources are represented in all plantings. One or two sources are represented in more than one series, and make possible some comparison between plantings of different series. This design kept the individual plantings small (3.2 acres maximum) and, because each series tested a specific effect, probably yielded most of the information that could have been obtained from much larger plantings.

This paper summarizes measurements taken through the 10th year in the longleaf and shortleaf plantations, and through the 15th year in the loblolly and slash plantations. Detailed analyses of all four species have been published elsewhere or are in press (Wells and Wakeley 1966, 1970a, 1970b; Snyder et al. 1967).

While the maxim, "local seed is best," has been a useful guide to southern tree planters for many years, the Southwide Study indicates that in some areas sizable genetic gain over local seed probably can be attained by moving seed considerable distances. In other situations, particularly near the northern limits of the species' ranges, no improvement over the local source appears possible.

The study was begun with the object of providing information to guide seed collection in natural stands. If tree improvement programs continue to develop at their present rate, it will be only a decade or so before most seed in the southern pine region is harvested from orchards rather than from natural stands. Results of this and similar research can then be used to guide the distribution of progenies from the orchards.

LOBLOLLY PINE

The loblolly pine phase of the study consists of 15 seed sources and 18 plantings distributed over the major portion of the loblolly range. The seed sources and plantings are divided into two series. Series-1 sources represent the major part of the range. Series 2, with the exception of the southeastern Louisiana seed source, is restricted to an east-west transect from North Carolina to Arkansas. The latest measurements were made during the winter of 1967-68, when the plantings were 15 years old.

Well-developed patterns of variation in survival, rust infection, and height growth are evident in both loblolly series.

On an average for all plantings, about 10 percent more trees from the two areas west of the Mississippi River (east Texas and southwestern Arkansas) survived than did trees from other sources. As drought is most common and most intense in the western part of the loblolly range, this variation seems the result of natural selection.

Trees from Maryland, southeastern Louisiana, and the two sources west of the Mississippi River are only lightly infected by the southern fusiform rust. Trees from the other sources, all east of the Mississippi River, are much more heavily diseased. In the 15 plantings where rust infections occurred, 11.6 percent of the trees from the four resistant sources were infected, as compared to 41.2 percent of the trees from the other sources.

In survival and rust infection, the interaction between seed sources and planting location was small and conformed to no discernible pattern. In height growth, the interaction was considerable and had a definite geographic pattern. In the majority of the plantings, trees from seed collected in areas with high summer rainfall and mild winters were tallest, but in the two coldest planting locations, Maryland and Tennessee, trees from such areas were outperformed by those from areas with low summer rainfall and cold winters. The general relationship between 15-year height and summer rainfall at seed source in Series 1 is illustrated in figure 1.

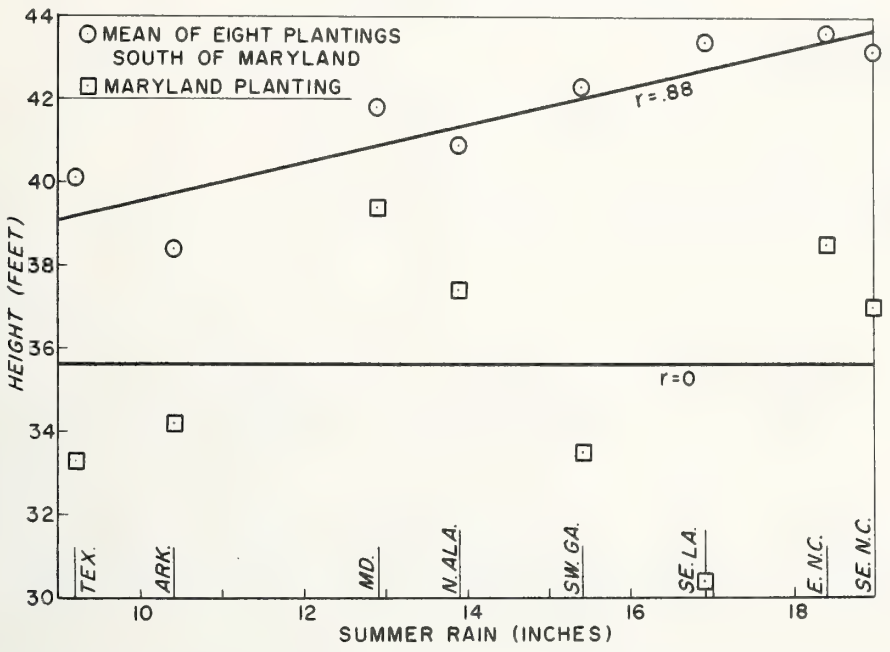

Figure 1.--Interaction of seed source × planting location in loblolly Series 1 at age 15 years.

There is little or no correlation among the three traits that vary geographically in loblolly--that is, trees with genetic potential for high survival, fast growth, and rust resistance do not occur in the same area. The trees from southeastern Louisiana do, however, combine fast growth and considerable rust resistance even though their survival has been only average. Therefore, use of seed from southeastern Louisiana is indicated in the area designated zone 2 in figure 2. More specifically, seed from southeastern Louisiana had best be collected from Livingston Parish (crosshatched area in zone 2). This was the source for the present study, and differences in rust susceptibility among loblolly pines from different parishes in southeastern Louisiana have been reported (Crow 1964). The northern limit of zone 2 was determined by good performance of the southeastern Louisiana trees in central Mississippi, central Alabama, and Georgia. The northeastern limit of zone 2 was set at the Georgia border because the Livingston Parish trees survived and grew less well in South Carolina and North Carolina than they did farther west. The western limit is set at the Mississippi River, as beyond that the frequency and intensity of droughts place a premium on survival.

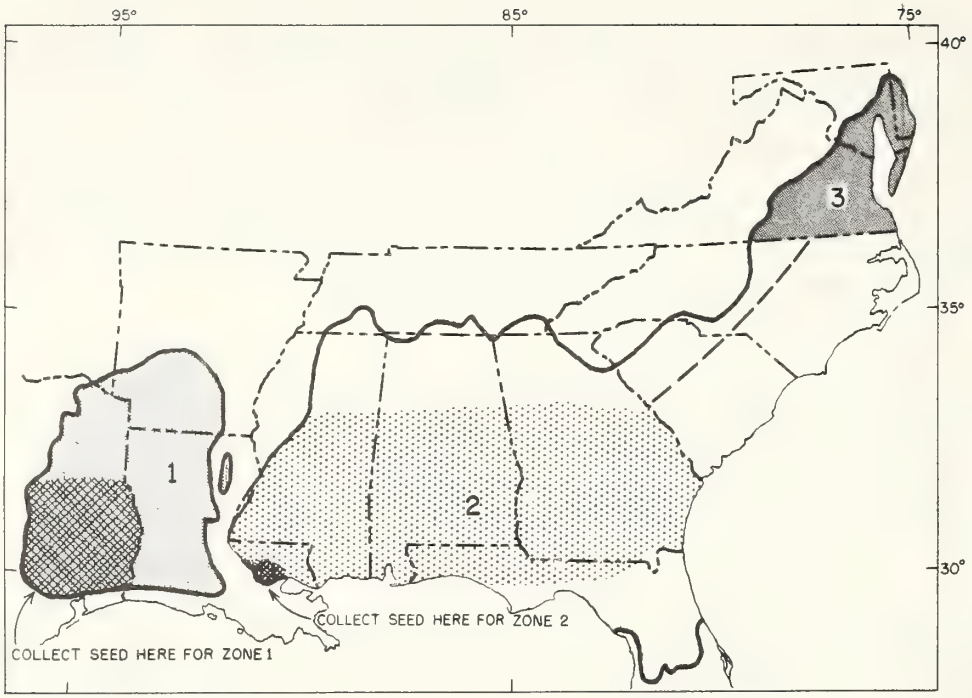

Figure 2.--Suggested seed collection and planting zones for loblolly pine. Natural range outlined by solid black line.

West of the Mississippi River the effect of latitude should be taken into consideration, as well as the likelihood of drought. There is a high probability of genetic variation in growth rate between the southern and northern populations. The Texas trees were taller than the Arkansas trees in the present study, even though they did not represent the southern extremity of the range in Texas. When the variation patterns for both survival and height are considered, it seems that loblolly seed for zone 1 should be collected south and west of the Sabine River (crosshatched area in zone 1). For plantings north of this zone, seed from north of the Sabine River would probably be better.

The network of plantings and seed sources is not as strong in North and South Carolina as it is in the Midsouth, but there is enough information from this and other work to show that Coastal Plain seed should be used only in the Coastal Plain and Piedmont seed only in the Piedmont. With this restriction, seed can probably be moved parallel to the coast anywhere within North and South Carolina; the dashed line in figure 2 divides the Coastal Plain from the Piedmont in this area.

In Virginia and northward the distance seed can be moved freely, without danger of growth loss, is much less than farther south; results in the Maryland planting clearly show this. "Collect seed in zone 3 for planting in zone 3" is probably a sound rule.

For planting north of zone 2 a TVA seed source study (Zarger 1961) clearly shows that inland sources (northern Mississippi, northern Alabama, northern Georgia, or the Piedmont of North and South Carolina) are best adapted.

SHORTLEAF PINE

The shortleaf pine phase of the study is considerably larger than the loblolly phase. It consists of 23 seed sources and 40 plantings distributed throughout the shortleaf range. The test is divided into six series of seed sources and plantings.

Plantations of the first three series were established during the winter of 1952-53, but losses from drought were so heavy that three more series were established in 1956-57. Though there are many exceptions, the last three series generally sample the same area as the first three, but the 10 surviving plantations from the first series constitute valuable replications by year. Thus, Series 1 and 4 sample the shortleaf pine range from near its southern extremity to near its northern extremity. Sources and plantings in Series 2 and 5 are in three distinct geographic areas: west of the Mississippi River, the southern Appalachian Mountains in Georgia and Tennessee, and the Allegheny Mountains in Pennsylvania. Series 3 and 6 test differences associated with longitude along a transect from southeastern Oklahoma to South Carolina.

The most important genetic variation has been in height and volume growth. Trees from the warmest parts of the range have excelled all others in Coastal Plain plantings up to 250 miles north of their point of origin. In the loblolly test more western than eastern trees survived, but in shortleaf the differences in survival have been small in all but the most northern plantings, where the superiority of the northern trees is striking.

The relationship between growth rate and temperature at seed source and the interaction between seed source and planting location are the dominant effects in the shortleaf test. Results in Series 4 are illustrative (fig. 3).

The two southernmost seed sources (southeastern Louisiana and southwestern Georgia) show a potential for fast growth that is well expressed in the southern plantings but not in the northern ones. In southern Mississippi, southeastern Louisiana, and southwestern Georgia (southern plantings in figure 3), trees from the two most southern sources in Series 4 average about 4 feet taller than the other trees.

In northern Mississippi, Tennessee, and North and South Carolina (middle-latitude plantings in figure 3) trees from southeastern Louisiana and southwestern Georgia still grow satisfactorily but are not as clearly superior to trees from other seed sources as they are in the most southern plantings. Still farther north, in Missouri and New Jersey, trees from southern sources grow considerably slower than more northern trees.

The strong relationship with temperature at seed source and the same interaction with planting location is also evident in Series 1, 2, and 5. For example, in all nine of the Series-5 plantings south of Pennsylvania trees from southern sources are taller than those from northern sources (fig. 4). In the

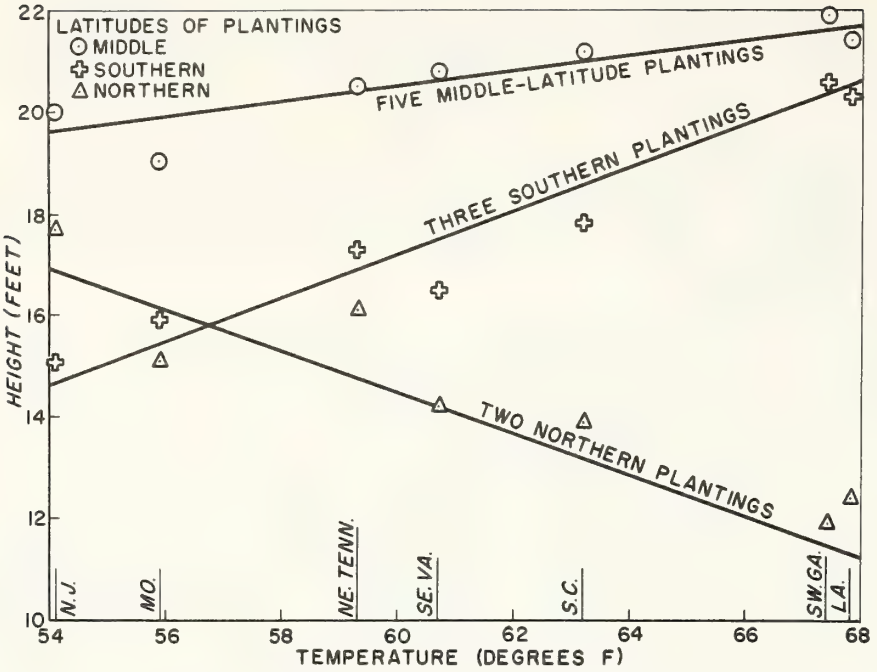

Figure 3.--Relationship between 10-year height and mean annual temperature at seed source in southern, northern, and middle-latitude plantings of shortleaf Series 4.

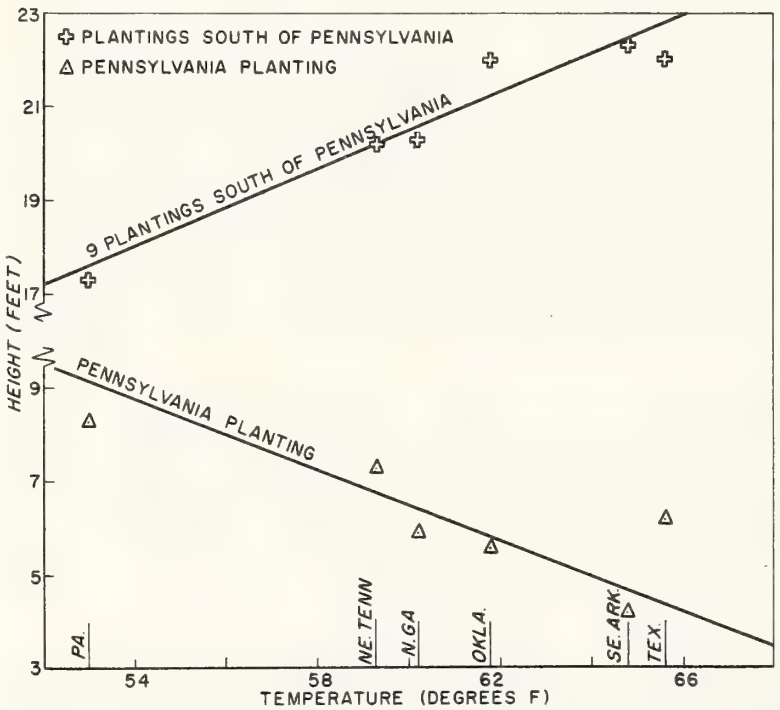

Figure 4.--Relationship between 10-year height and mean annual temperature at seed source in a Pennsylvania planting and in nine plantings to the southward. Shortleaf Series 5.

Pennsylvania planting the pattern is completely different. Survival and growth have been poor throughout this planting but the superiority of the northern, particularly the Pennsylvania trees, is obvious.

Figure 4 also illustrates another, more subtle, effect. In the nine plantings south of Pennsylvania, when trees from all six seed sources from Pennsylvania to Texas are considered, the relationship between height and climate at seed source is clearcut. This relationship is not evident, however, when only the trees from the three most western sources are considered; they are all about the same height in spite of a difference of 3.8° in mean annual temperature at seed source.

Shortleaf Series 3 and 6, 12 plantings in all, have revealed that very little genetic variation is associated with longitude along an east-west transect from southeastern Oklahoma to South Carolina.

Two results from the shortleaf phase of the study lend themselves to forestry practice: (1) the tendency for trees from the two southernmost seed sources east of the Mississippi River to grow faster than those from northern sources in southern plantings and in plantings as far north as northern Mississippi, and (2) the superiority, in terms of both growth and survival, of trees from the most northern sources in the plantings near the northern extremities of the species' range. In the middle of the range, on both sides of the Mississippi River, the relationship between growth in the test plantings and temperature at seed source does not seem strong enough to be of practical value.

Tentative seed-collection and planting zones are mapped in figure 5. If

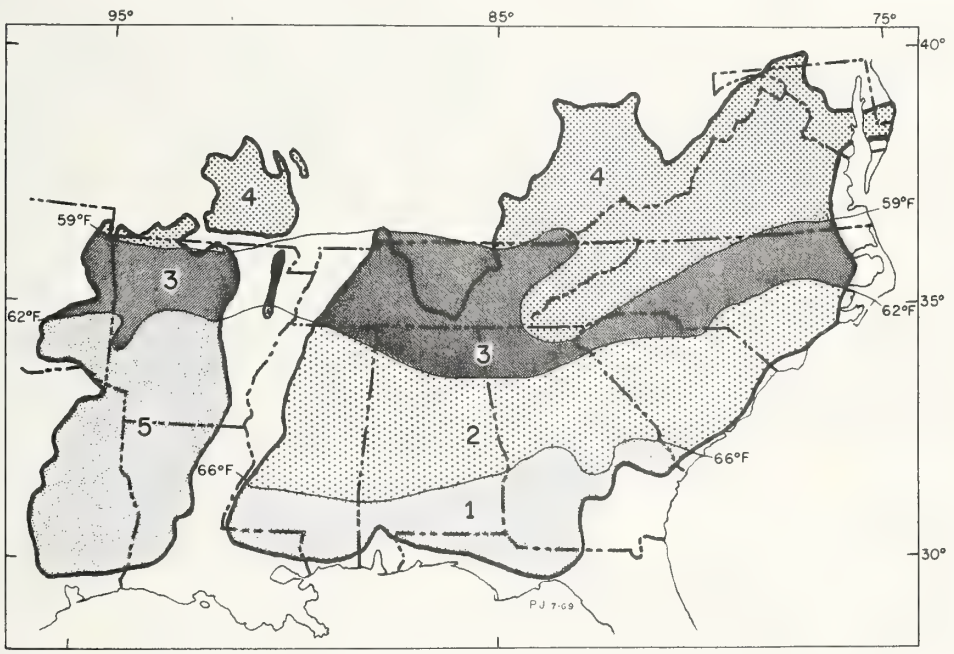

Figure 5.--Suggested seed-collection and planting zones for shortleaf pine, with isotherms of average annual temperature. Natural range is outlined by heavy black line.

shortleaf pine plantings are to be made in zones 1 or 2, seed should be collected in zone 1. In six plantations in zone 2, trees from zone 1 sources had about 17 percent more volume than trees originating in zone 2. Seed from zone 5 would very likely also be a good choice for planting in zone 2. For planting in zone 3, seed can be collected in either zones 2 or 3 or in the northern half of zone 5. Seed for planting in zone 4 and beyond should be collected only in zone 4. In the three zone-4 plantings in this study, trees from zones 3, 2, and 1 had 27, 48, and 76 percent less volume, respectively, at age 10 than trees from zone 4.

LONGLEAF PINE

The longleaf phase of the Southwide Study is similar in design to the shortleaf phase in that there are six series of seed sources and plantings; the plantations were established in 1952-53 and 1956-57. Series 1 and 4 sample the longitudinal range of the species from central Georgia to eastern Texas. Series 2 and 5 test two major influences that could be expected to cause genetic variation: one is the difference in climate between the Carolinas and the central Gulf Coast; the second is soil type--sandhill soils or Coastal Plain soils. Series 3 and 6 sample the northern, western, and southeastern extremities of the range and three intermediate points; they were designed to test the influence of climatic extremes within longleaf's range. In all, there are 15 seed sources and 35 surviving plantations.

After 10 years, geographic patterns of variation were evident in survival, initiation of height growth, total height, volume, and infection by brown spot.

Survival of the 32,900 seedlings originally planted in 1956-57 averaged 71 percent after 3 years, 69 after 5 years, and 57 at age 10. Trees from the two most westerly sources, central Louisiana and eastern Texas, survived well for 3 years but suffered proportionately more mortality between the fifth and 10th year than did trees from other sources. The western sources were also more heavily infected by brown spot than those from the central part of the range. These findings suggest a cause-and-effect relationship between brown spot susceptibility and survival.

As judged by height growth and volume at age 10, trees from southern Florida performed poorly in all plantings. Gulf Coast trees from southern Mississippi, southern Alabama, and western Florida grew faster than other trees in plantings 150 miles north and 250 and 300 miles east and west of the point of origin. Farther north and west, trees of more local origin performed as well as or better than those from the central Gulf Coast.

Height growth and volume per acre of the southern Alabama trees, for example, were outstanding in most of the Series-1 and -4 planting locations (fig. 6). Growth rate of trees from southern Alabama was well above average as far west as central Louisiana (Rapides Parish) and in central Alabama up to about 150 miles north of the Gulf Coast (Perry and Autauga Counties). Ninety miles still farther north in Alabama, however, growth rate of southern Alabama trees was below average. The northernmost Alabama planting is on the Piedmont Plateau, where average annual temperature is 62.3° F. and the elevation is about 1,400 feet. The central Alabama plantings are in the Prairie Belt at an elevation of

less than 500 feet; average annual temperature is 64.0°. The southern Alabama seed source is on the Coastal Plain near sea level, and average annual temperature is 67.3°. Thus it has proved advantageous to move southern Alabama seed northward about 3° of average annual temperature but not 5°.

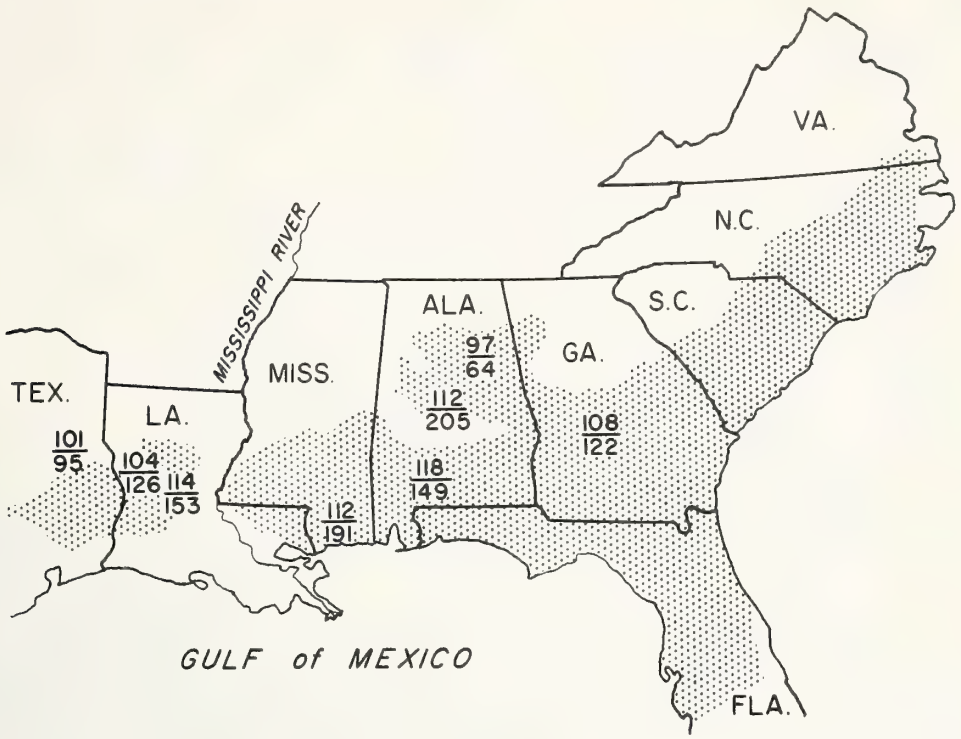

Figure 6.--Tenth-year height (numerator) and volume per acre (denominator) of longleaf pines from southern Alabama seed, expressed as percent of mean of trees from all seed sources represented in planting. Position on map indicates planting location, and the stippled area represents the natural range. Series 1 and 4 combined.

The southern Alabama trees are only performing slightly better than average in central Georgia, but in the more northern plantings of Series 2 and 5, near the North Carolina-South Carolina border, they are outgrowing local stock.

Trees from southeastern and central Louisiana ranked low in 10th-year height and volume in all plantings.

Taking results from all series into consideration, it is possible to map the zone within which trees from Gulf Coast seed sources have performed better than trees from other sources. If plantings are to be made in the area signified by the stippling in figure 7, collecting the seed from the hatched area (central Gulf Coast) seems advisable.

West of the stippled area in figure 7, seed from west of the Mississippi River is indicated. From present data the Texas counties of Polk, Tyler, and Hardin appear a better source than central Louisiana. The data do not define any "best" seed source for areas north or west of the stippled area. They do, however, show that there is no advantage in moving longleaf seed north more than 4° of average annual temperature. Reference to the isotherms of mean annual temperature in figure 7 will aid in making decisions along these lines.

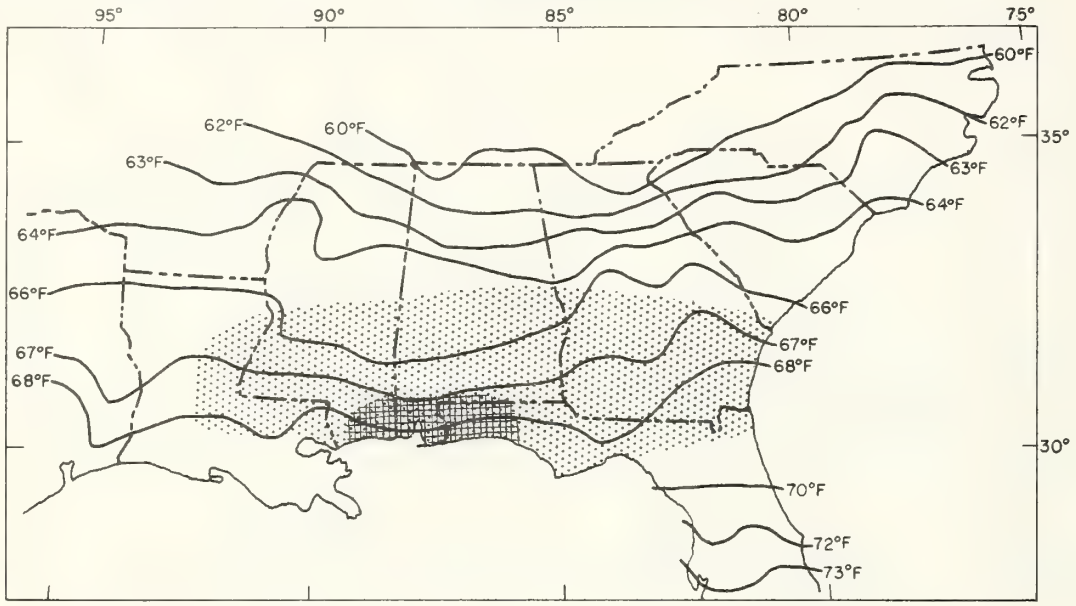

Figure 7.--Optimum longleaf seed-collection area (hatched) for plantings to be made within stippled area. Isotherms of average annual temperature are shown.

Moving longleaf seed from southern Florida into northern Florida or beyond is inadvisable. Present indications are that such a shift would result in almost complete failure.

The longleaf test also indicates some other combinations of seed sources and plantings that should be avoided if at all possible, as they are likely to occasion a growth loss of perhaps 10 or 20 percent. Thus, seed collected west of the Mississippi River should not be used east of the river. Seed from southeastern Louisiana seems a poor choice for use anywhere, unless further research shows that the two collections made for the present study are not representative. Seed from near the extremity of the range in northern Alabama should not be moved south or east more than about 150 miles, and it should particularly not be used near the central Gulf Coast. Similarly, seed from near the northern extremity of the range in Virginia or northeastern North Carolina should probably be avoided. Sources nearer the North Carolina-South Carolina border would be a better choice for plantings anywhere in the northeastern part of the natural range.

SLASH PINE

The slash pine phase of the study consists of trees from six seed sources planted in eight areas. Seed was collected in 1951 and plantings established in 1952-53.

By far the largest genetic variation was the poor survival and growth of trees from the southern Florida source (Polk County) in all plantings. The differences among the other sources, which are distributed in an east-west transect across the species' range, were generally small, but some differences between the northeastern Florida source and the other sources are of biological and probably economic significance. Most important, the northeastern Florida stock did not survive as well in some plantings as did stock from sources farther to the west or northeast. A good illustration occurred in Sabine Parish, Louisiana, where an adverse site, combined with drought during 1953, lowered overall 10th-year survival to 35 percent. Under such severe conditions the superiority of sources other than northeastern Florida was particularly well expressed (fig. 8). A similar result had been demonstrated previously in six other seed-source plantings established between 1937 and 1948 (Snyder et al. 1967). All of the earlier plantings, like the one in Sabine Parish, were well outside the natural range of slash pine. Within the range survival differences are smaller.

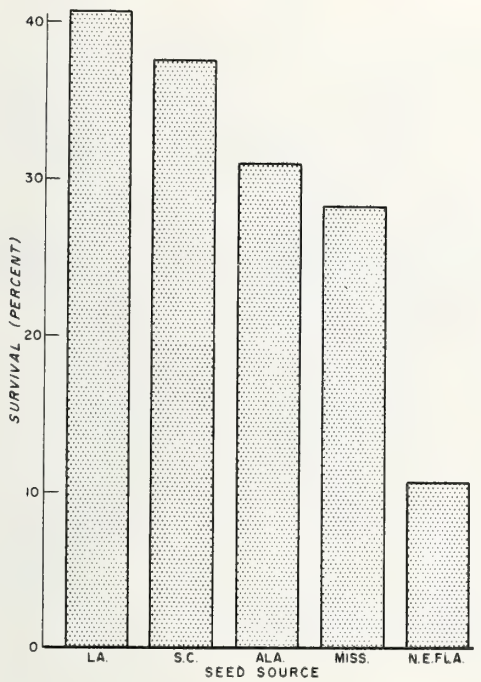

Figure 8.--Tenth-year survival, in a western Louisiana planting, of slash pine from five seed sources.

Two other Southwide Study plantings provided additional evidence of genetic differences between northeastern Florida slash pine and sources farther west and north. In Georgetown County, South Carolina, an ice storm in March 1962 damaged almost twice as many northeast Florida (Baker County) trees as it did trees of any other source. Also, when hogs rooted in the Baker County, Florida, planting in 1959, the local stock was significantly less damaged than that from Polk County, but significantly more damaged than the South Carolina, Louisiana, and Alabama trees, which were scarcely touched.

These variations all indicate that the northeastern Florida source is more like the southern Florida source than are the Louisiana, Mississippi, or South Carolina populations. The survival and ice-damage data indicate that trees from north or west of northeastern Florida would be more suited for planting north or west of the species' range or on droughty sites anywhere that use of the species is contemplated.

The performance of the northeastern Florida trees is of particular value for judging the suitability of seed collected from planted stands of unknown seed source, because almost all of the slash pine plantings established before

1940 and many established even later were from seed collected in northeastern Florida and south Georgia. On the basis of the present results, trees from seed collected in these old plantings would be less suitable for planting north or west of the natural range than trees of more western or northern provenance.

The only height differences evident in the Southwide slash pine plantings are attributable to the southern Florida seed source, which by virtue of its low survival was poorly represented in most of the plantings. Except locally, where their performance was average, trees from the southern Florida source grew relatively slowly in all plantings where enough of them survived to make a comparison possible.

Tests currently in progress at the Southeastern Forest Experiment Station sample the slash pine range much more thoroughly than did the Southwide Study and have shown genetic differences in height growth. The geographic pattern of this variation is complex, but the poor performance of the southern Florida trees when they are moved north is a strong feature of it (Squillace and Kraus 1959; Squillace 1966). The east-west component of the variation in height is much smaller than the north-south component in both the Southwide and the Southeastern Station study.

RELIABILITY OF RESULTS

In conclusion, it is evident that the 10-year data on disease resistance and survival for all species are as reliable and useful as anything that is likely to be obtained from future reexaminations. In height and volume growth some changes from present patterns may occur, but the plantings have grown through a third to a half of a pulpwood rotation with no drastic reversals in ranking of individual sources. The basic patterns of variation that first appeared are still present and, most important, there have been no instances of outright cold-induced injury when southern sources have been moved northward within the limits suggested in this paper. Such injury has occurred only in the Missouri, Pennsylvania, and New Jersey plantings, which are the most northern in the study. In other plantings trees moved too far north have responded only by growing slowly.

The plantings also have withstood some severe weather. Three events in particular put them to a harsh test:

> The drought west of the Mississippi River during 1950-56, which was one of the worst on record in the area.
>
> An extremely destructive freeze late in March 1955, after an extended warm period. All plantings established in 1952-53 were exposed.
>
> The cold winter of 1962-63, which brought alltime record or near-record low temperatures to all plantings in the study.

The ability of trees from areas of relatively mild climate to withstand these events seems strong evidence in favor of the present proposals for seed movement.

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PHENOTYPIC AND GENOTYPIC VARIATION IN EASTERN COTTONWOOD IN THE SOUTHERN GREAT PLAINS

Clayton E. Posey 1/

The demand for wood cellulose is ever-increasing and is expected to more than double the present usage before the end of this century. Where will the wood be produced considering competition for land by urban sprawl, lakes, highways, recreational areas, and agricultural crops? One possibility would be the utilization of land suitable for cottonwood (Populus deltoides Bartr.) production which exists along streams and on sub-irrigated soils throughout the Great Plains region.

This paper reports, in general terms, variation in cottonwood along a portion of the western edge of the species range. The pattern of natural variation in specific gravity, fiber length, and diameter growth rate is presented first, followed by variation observed in fiber length, specific gravity, fiber diameter, microfibril angle, gelatinous fibers, lean, diameter growth, height growth, limbs/foot, and sprouting ability for 200 plus clones grown at one location.

METHODS

Plot and Environmental Description

Twenty-four plots were established, each approximately 60 miles apart, along the Red, South Canadian, and Cimarron Rivers from the Oklahoma-Arkansas state line westward, about 600 miles, to the headwaters. In addition, for comparative purposes, a single plot was sampled on the Mississippi River east of Dewey, Arkansas.

The plot locations, except for the Mississippi plot, are characterized by the following environmental conditions:

a. Average annual rainfall for the five-year period during which the wood evaluated was formed ranged from 48.8" in the southeast to 13.8" in the northwest.
b. Elevation from 310 feet in the southeast to 6500 feet in the northwest.
c. Average number of frost-free days from 240 in the southeast to 175 in the northwest.
d. Minimum temperature for January from 3°F. in the southeast to -28°F. in the northwest.
e. Maximum temperature for August from 120°F. in the southwest to 102°F. in the northwest.

1/ Associate Professor, Forest Genetics, Department of Forestry, Oklahoma State University, Stillwater, Oklahoma.

Field Sampling

At each plot two 12-millimeter increment cores were extracted from the bark to the pith on opposite sides of each of ten dominant trees. Twenty cuttings were taken from the most vigorous portion of the crown of each sample tree.

Age of tree at breast height was determined by ring count. Annual rings for a five year period (Years 3-7) were cut from the core and measured for an estimate of radial growth rate. Specific gravity was then determined for each five-year core, utilizing the maximum moisture content method, as outlined by Smith (1954). The sixth and seventh annual rings were cut from the core and macerated using the procedure described by Franklin (1945). The length of twenty whole fibers were measured for each sample.

Field Planting

The twenty cuttings from each sample tree were planted near Norman, Oklahoma during April 1967. The planting design was a split-plot with four replications. Each replication contained a five ramet row plot for each of the ten clones from the 25 geographic sources grouped by clones within sources. Spacing between rows was 24 inches and within rows was 18 inches.

After the end of the first growing season, height, diameter at 20 inches above the ground, and number of limbs per foot were determined for all clones. Stem cross sections were also taken at 20 inches above ground from all clones for specific gravity determinations.

For an intensive wood study, samples were taken from four ramets from each of forty-three clones representing seven geographic sources along the Red River. Fiber lengths, fiber diameters, microfibril angle, percent gelatinous fibers, and degree of lean were measured for each ramet.

All of the one year old trees produced from cuttings were harvested and used in field plantings. The one year old stumps were allowed to sprout for production of additional cuttings. In August 1968 the number of sprouts per stump were counted to determine geographic variation in sprouting.

This paper is intended to be general and cover a wide range of variables. For this reason, much of the information presented is based on geographic source averages. Detailed information about procedures and results will appear in other publications.

RESULTS

Specific Gravity

Specific gravity of the wood from natural stands, based on plot means, ranged from 0.36 for a plot in New Mexico on the Cimarron River to 0.45 for a plot in south central Oklahoma on the Red River. The trees with lowest specific gravity from six sources on the Canadian River had higher specific

gravity than the high specific gravity trees from the Mississippi source (0.35). On an individual tree basis, specific gravity ranged from 0.30 to 0.50. The mean for all sources combined, except the Mississippi source, was 0.404.

In general, specific gravity of the wood along all three rivers was lowest in the east and increased toward the west. The linear correlation coefficient between specific gravity and longitude was 0.47, significant at the 005 level of confidence. Specific gravity by rivers was lowest for the Red (0.39) and highest for the Canadian (0.42).

When all clones were grown at one location, then compared for specific gravity, the same relative geographic source pattern as stated for natural stands was observed. Specific gravity, based on geographic source means, ranged from 0.35 to 0.41. Based on clone means specific gravity ranged from 0.30 to 0.47. Specific gravity increased from 0.35 for sources in eastern Oklahoma to 0.40 for sources in western Oklahoma. Clones from the Texas and Oklahoma Panhandles, New Mexico, and Colorado tended to have lower specific gravity than clones from western Oklahoma. This decrease in specific gravity for clones from the extreme western portion of the range was probably a result of low vigor exhibited by clones that had been moved hundreds of miles from their native habitat. Clones from the Red River had average specific gravity of 0.37, whereas, clones from the Canadian and Cimarron Rivers averaged 0.38.

Fiber Length

The length of fibers, based on plot means, ranged from 0.94mm to 1.28mm. Fiber length based on tree means ranged from 0.88mm. to 1.42mm. The mean for all sources was 1.07mm. Fiber length of trees along the Red River exhibited a linear east-west trend with fiber length decreasing from 1.28mm. in eastern Oklahoma to 0.98 in the Texas Panhandle. A decrease in fiber length from east to west was not evident for the Canadian and Cimarron Rivers. The mean fiber length for the Mississippi River source (1.06mm.) was about the same as the overall mean for the Red, Canadian, and Cimarron Rivers (1.07mm.).

The length of fibers of clones grown at one location ranged from 0.61mm. to 0.85mm. Variation in fiber length, based on geographic source means, ranged from 0.67 to 0.81. In considering fiber length from the Red River only, the linear correlation coefficient between longitude and fiber length is -0.85 significant at the 0.05 level of confidence.

Diameter and Height Growth Rate

Diameter growth rate stated here for natural stands is based on the amount of increase in diameter inside bark for years 3 through 7 from the pith. Based on geographic source means, diameter growth ranged from 7.0 inches in five years for a source on the Red River in southeastern Oklahoma to 1.7 inches in five years for the source representing the extreme western edge of the range on the Canadian River. Diameter growth for a five year period based on individual trees ranged from 11.0 inches to 0.8 inches.

Differences in diameter growth of trees between rivers were quite large, being significant at the 0.025 level of confidence. Trees on the Red River grew 70 percent faster than trees on the Canadian and 25 percent faster than trees on the Cimarron.

Along all three rivers there was a definite decrease in rate of diameter growth from east to west ($r = -0.65$).

When all clones were grown at one location the same east-west trend in diameter growth rate occurred. Clones from eastern Oklahoma tend to grow faster in diameter than clones from the extreme western edge of the species range.

Based on geographic source means, diameter growth ranged from 0.56 to 0.94 inches after one growing season. Diameter growth rate based on clone means ranged from 0.2 to 2.0 inches.

Height growth exhibited the same east-west pattern as stated for diameter growth. Trees from the extreme western edge of the range tend to grow as fast as trees from eastern Oklahoma until about mid-summer when height growth of trees of western origin tends to decline or for some clones ceases.

Based on geographic source means there is a 30 percent difference in height growth between the best source and the poorest source. Based on clone averages the best clone is 110 percent superior in height growth as compared to the poorest clone.

Fiber Width and Microfibril Angle

Width of fibers and the orientation of microfibrils in the cell wall varied very little between geographic sources. Fiber width based on source means ranged from 19u to 20u. Differences based on clone means ranged from 17u to 21u.

Microfibril angle, based on geographic source means, ranged from 20.1 to 22.0 degrees. Based on clone means microfibril angle ranged from 17.2 to 26.9 degrees. A geographic pattern for fiber width and microfibril angle variation was not evident.

Gelatinous Fibers

The percentage of gelatinous fibers present in the sample cross-section increased from east to west. Gelatinous fibers, based on geographic source means, ranged from 21.3 to 30.1 percent and based on clone means, ranged from 14.5 to 39.3 percent. The increase in amount of gelatinous fibers from east to west is due, in part, to an increase in amount of tree lean from east to west.

Limbiness of Trees

One of the most striking differences between clones and between geographic sources is the variation in number of limbs. On the Red River the number of limbs per foot, based on source means, ranged from 1.5 in the east to 4.1 in the west. Based on clone means, the number of limbs per foot ranged from 0.6 to 5.7. It is not known at this time the exact influence of these limbs on wood quality. All limbs may not persist for a long period of time; but if the strong geographic pattern remains, wood quality would certainly be affected.

Number of Sprouts per Stump

From the standpoint of cutting production in the nursery or cellulose production on short rotations, the sprouting habit of different clones and geographic sources is very important. Sprouting habit followed the same geographic pattern as stated for number of limbs. Based on geographic source means the number of sprouts per stump ranged from 4.6 to 8.7.

Drought Resistance

Drought resistance as used here means that a clone has the capacity to survive in the following environment:

a.	Elevation	2300 feet
b.	Annual rainfall	23 inches
c.	Soil	Sand dune greater than 48" in depth
d.	Site	Subject to high velocity, hot, dry winds during growing season

Sixty-nine clones, each represented by twenty, 20-inch cuttings, were tested. At the end of the first growing season over 50 per cent of the clones had zero survival. One clone had 100 per cent survival. Clones originating in western Oklahoma tended to survive better than clones from eastern Oklahoma although several promising clones from eastern Oklahoma were observed.

CONCLUSIONS

This study has shown wide variations between geographic sources and between trees in stands for many economically important traits. These geographic differences parallel environmental gradients. The environmental differences, through natural selection, have caused genetic variation to occur between different geographic localities.

Genetic variation between geographic sources is of sufficient magnitude for growth rate, fiber length, tree lean, gelatinous fibers, number of limbs per foot, sprouts per stump, drought resistance, and specific gravity, that geographic origin must be considered in a cottonwood selection and breeding program.

Trees from eastern Oklahoma tend to have longer fibers, lower specific gravity, faster growth rate, straighter stems, fewer gelatinous fibers, fewer limbs, fewer sprouts per stump, and be more susceptible to drought than trees from western Oklahoma. Western Oklahoma cottonwood can be used to increase specific gravity and drought resistance of trees grown in the eastern part of the state and trees from the eastern part of the state can be bred with western Oklahoma trees to increase growth rate and wood quality of trees to be grown in western Oklahoma.

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PATHOGENIC VARIABILITY IN CRONARTIUM FUSIFORME

G. A. Snow, H. R. Powers, Jr., and A. G. Kais[1/]

Investigations are in progress at the Southern and Southeastern Forest Experiment Stations to determine if pathogenic variability exists in Cronartium fusiforme Hedgc. & Hunt ex Cumm. The likelihood that such variability occurs has been suspected for some time, and was strengthened by the recent discovery of variability in C. quercuum (Berk.) Miyabe ex Shirai (Kais and Snow 1969; Powers 1969), a less important pine-oak rust fungus found within the range of C. fusiforme. This paper reviews results from recently completed or current studies at the two stations.

At the Southeastern Forest Experiment Station, seedlings of several southern pine species were inoculated with four isolates of Cronartium spp. The isolates were obtained from: (1) a cerebroid gall on a loblolly pine in the upper Piedmont of South Carolina, (2) a fusoid gall on a loblolly pine in the same part of South Carolina, (3) a fusoid gall on a Sonderegger pine in south Mississippi, and (4) a cerebroid gall on a loblolly pine near Charleston, South Carolina. Inoculations were made by suspending telia-bearing oak leaves over potted pine seedlings, according to the method devised by Jewell (1960).

There was no significant pathogenic variability among these isolates (table 1). The proportion of plants of each species developing galls was approximately the same for each isolate, and the galls which developed were for the most part spindle-shaped. Although the results are in general agreement with the data for Cronartium fusiforme published by Hedgcock and Siggers (1949), some discrepancies exist. Probably the most noteworthy difference is that these authors found pond pine to be as susceptible as slash pine, whereas in the present data it appears highly resistant to all four rust isolates. The highest infection on this species was 7 percent.

Originally it was thought that the two isolates from cerebroid galls were possibly Cronartium quercuum. The fact that inoculations with all four isolates resulted in primarily fusoid galls suggests that they were all C. fusiforme, and that gall shape cannot be used to distinguish C. quercuum from C. fusiforme on loblolly pine.

In a current study at Gulfport, five selections of pine seedlings were inoculated with isolates of Cronartium fusiforme. Included were susceptible slash pine, resistant slash pine, susceptible loblolly, resistant loblolly, and shortleaf. The slash pines were from seed of one resistant and one susceptible tree in Mississippi; the trees had been wind-pollinated. The loblolly seed was from control-pollinated trees in south Louisiana, and the shortleaf seed was a bulk

1/ G. A. Snow and A. G. Kais are stationed at the Forest and Wood Products Disease Laboratory, Southern Forest Experiment Station, USDA Forest Service, Gulfport, Mississippi. H. R. Powers, Jr., is stationed at the Forestry Sciences Laboratory, Southeastern Forest Experiment Station, USDA Forest Service, Athens, Georgia.

Table 1.--Percentage of pine seedlings which developed fusiform rust galls after inoculation with Cronartium fusiforme from three geographic sources

Pine species	Sources of inoculum[1/]							
	South Carolina (1)		South Carolina (2)		Mississippi		South Carolina (3)	
	Percent	No. seedlings	Percent	No. seedlings	Percent	No. seedlings	Percent	No. seedlings
Loblolly (*P. taeda* L.)	28	222	45	337	27	122	35	255
Slash (*P. elliottii* var. *elliottii*)	53	301	42	289	48	205	58	481
South Florida slash (*P. elliottii* var. *densa* Little & Dorman	82	216	82	113	76	68	85	128
Shortleaf (*P. echinata* Mill.)	1	347	4	279	4	73	0	311
Virginia (*P. virginiana* Mill.)	2	579	1	603	2	129	0	296
Spruce (*P. glabra* Walt.)	...	...	0	169	0	87	0	106
Pond (*P. serotina* Michx.)	0	24	1	404	1	198	7	307
Sand (*P. clausa* (Chapm.) Vasey)	3	209	0	211	0	78	0	241

1/ South Carolina isolates (1) and (3) were collected from cerebroid pine galls; other isolates were from fusoid galls.

collection from Tennessee. The degree of susceptibility of the pine selections had been determined by inoculating other progenies of these seed sources (the determinations were by the Institute of Forest Genetics at Gulfport). Three separate isolates of C. fusiforme were obtained from fusoid galls on loblolly or slash pine at each of five locations: (1) Nacogdoches, Texas; (2) Saucier, Mississippi; (3) Perry, Florida; (4) Auburn, Alabama; and (5) Raleigh, North Carolina. Eighteen 5- to 7-week-old seedlings of each pine selection were inoculated with each of the 15 rust isolates. Inoculation of the plants was accomplished with an apparatus that closely controlled spore deposition on each plant (Snow 1968). Seedlings were grown in the greenhouse and examined for galls 6 months after inoculation.

The susceptible slash and loblolly selections became uniformly infected by all rust isolates (table 2). The shortleaf seedlings were resistant to all the isolates.

Table 2.--Percentage of resistant and susceptible pine seedlings with fusiform rust galls 6 months after inoculation with Cronartium fusiforme from five geographic sources[1/]

Selection of pine	Sources of inoculum				
	Texas	Mississippi	Alabama	Florida	North Carolina
	Pct.	Pct.	Pct.	Pct.	Pct.
Susceptible slash	96	96	100	100	96
Resistant slash	41	50	96	94	63
Susceptible loblolly	98	98	98	100	100
Resistant loblolly	63	62	63	39	35
Shortleaf	0	0	0	0	0

1/ Percentages were calculated for surviving plants of the 54 inoculated (three isolates from each source × 18 seedlings).

The resistant selection of slash pine showed moderate resistance to the Mississippi, Texas, and North Carolina isolates, but was highly susceptible to isolates from Alabama and Florida. Analysis of variance showed that this difference between sources was significant.

The resistant loblolly seedlings varied considerably in response to the individual isolates from each source, but the difference between sources was not significant.

Preliminary analyses of data taken 9 months after inoculation show that the trends described here have continued.

To summarize, we have found no evidence of variability in Cronartium fusiforme which is of a magnitude that can be detected with different species of pine. However, the differences which we have observed in the capacity of rust isolates to infect resistant within-species selections of pine indicate that pathogenic variation does exist in C. fusiforme. The importance of this variation in tree breeding programs remains to be determined.

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ELECTROPHORESIS SEPARATION OF GENERAL PROTEIN AND ISOENZYMES OF BLACK CHERRY SEED (PRUNUS SEROTINA EHRH.) [1]

Ralph A. Lewis and Franklin C. Cech [2]

In addition to seed source studies, biosystematic investigations which describe patterns of variation through comparative anatomy, morphology, biochemistry or related disciplines, provide valuable data on the geographic variation of a given species. In 1966, a comprehensive study of black cherry (Prunus serotina Ehrh.) was initiated at West Virginia University. Initially, seeds from 33 widely separated areas throughout the black cherry range were collected, studied, and planted. Geographic differences in seed characteristics were found (Cech and Kitzmiller, 1968). Several outplantings have been made for future analyses.

As part of this continuing study, a limited biochemical investigation was made on dormant black cherry seeds. Variations in electrophoretic patterns of general protein and selected enzymes were studied as to their possible relationship with geographic origin. The primary analytical method in this study was polyacrylamide gel, "disc" electrophoresis, which utilizes small gel columns as the support media for sample protein migration and separation. This method, and other techniques of zone electrophoresis have been utilized in many studies of biochemical variations in plant and animal tissues.

Clements (1965) was able to demonstrate unique and reproducible patterns for ovary protein extractions of varieties of apples, pears, oranges, lemons, avocado, and bananas. Significant differences in esterase patterns of certain pea varieties were found by Frankel and Garber (1965). In comparative electrophoretic studies of the seed proteins from certain species of Brassica and Sinapis, Vaughn and Waite (1967) found evidence which supported the established taxonomy of these species. A later study (Vaughn and Waite, 1967) of certain amphidiploid species of Brassica revealed that the hybrids had bands from "both suspected parents," but a few new protein systems were thought to have been evolved as a result of hybridization.

The methods of gel electrophoresis lend themselves readily to many types of research in higher plants (Brewbaker, 1968). Even though the number of plant enzymes that may be easily detected by such methods are limited, genetic polymorphisms of these enzymes are sufficient for comprehensive studies of angiosperm systematics, morphogenetics, and physiology.

1/ Approved by the Director of the Agriculture Experiment Station as Scientific Paper No. 1080.

2/ Respectively Graduate Research Assistant and Forest Geneticist, West Virginia University Agriculture Experiment Station.

METHODS AND PROCEDURES

This study was divided into three phases:

I. The testing, modification or development of satisfactory techniques.

II. A comparative study of materials from the same general geographic area.

III. A comparative study of material from selected sources throughout the natural range of the species.

This paper will present information on phases I and II. The analysis of phase III data has not been completed.

PHASE I

A preliminary consideration was the need for a method for removing the hard coat of black cherry seed. A seed splitter was fabricated from a tubing cutter with a movable cutting wheel. With this device, the seed coats could be split easily and quickly, without damaging the soft interior.

After removing the coats, the embryo and endosperm were ground into a fine powder and an appropriate solvent was used to extract the soluble protein. Various solvents were tested; aqueous buffers were most satisfactory. Of these, a 0.2 M (pH 8.5) tris borate buffer gave the best results and was utilized for all subsequent extractions. A minimum extraction time of 12 hours was used. Seeds and extracts were stored at 5°C.

Brewbaker's (1968) use of refinement procedures in the preparation of soft tissues of root, leaf and endosperm afforded little advantage. Nevertheless, in an attempt to obtain gels of higher resolution, gel filtration (Bio-gel), high speed centrifugation, ion exchange chromatography, sucrose density gradients (ultracentrifuge at 100,000 x G) and salt precipitation were tested. High speed centrifugation (25,000 x G for 15 minutes) was found to be a simple and effective purification method and was incorporated in the extraction procedure.

The filtered extracts were assayed for protein content against a bovine serum albumin standard using the assay procedure of Lowry et al. (1951). Each extract was adjusted to a protein content of 3.3 mgms/ml with a 3 M sucrose solution.

General protein and enzyme systems (acid phosphatase, amylase, catalase, esterase, leucine amino peptidase, and peroxidase) were investigated. Amylase and catalase studies were discontinued due to staining difficulties.

The electrophoretic chamber was manufactured by Buchler Instruments Inc. under the trade name "Polyanalyst." It is a compact, 12 tube instrument with a water jacket around the lower buffer chamber for temperature regulation. A jacket was added around the upper chamber so that the entire apparatus could be cooled during a run. Electrical current was supplied by a model EC 454 D.C. power supply (E.C. Apparatus Corp.).

Anionic buffer and gel systems were used, with the protein migrating down the gel columns toward the positive electrode. The columns were contained inside standard wall glass tubes with an 8 mm outside diameter and a length of 95 mm. With minor modifications, gels were prepared using the procedures developed by Davis (1964). Acrylamide contents of 5%-15% and various gel formulations were tested. A 7% acrylamide content was found to be most satisfactory. Four different gel formulations were used in the study, the specific formulation depending on the type of material to be elucidated. This was also the determining factor for the type and composition of the buffer(s) used.

The same gel and buffer systems were used for general protein and peroxidase. Different systems were used for acid phosphatase, esterase, and leucine amino peptidase. In some instances, modification of formulations found in the literature improved the pattern resolution. Gel and buffer references with the modifications for this study are presented (Table 1).

Table 1.--Gels & Buffers: References and Modification

Material to be stained	Formulation References	Modification of Ref. Formulations
General Protein and Peroxidase	Gels..Davis(1964)	Running gel - 1 part Stock Soln. (A); 1 part Stock Soln. (C); 2 parts small pore solution #2
		Stacking gel - Sub. 3 M sucrose soln. for Stock Soln. (F)
	Buffers..Polyanalyst Instruction Manual (Anonymous, 1966)	None
Acid Phosphatase	Buffer & Gel: Williams & Reichfeld (1964)	None
Esterase Leucine Amino Peptidase	Buffer & Gels: Brewbaker (1968)	Gels: Reduce ammonium persulfate solution from 10% to 2.5%

Except for general protein gels, the protein samples were applied directly to the top of the 7% running or separation gel. In the case of general protein, a 2.5%, light polymerized stacking gel was layered on top of the running gel before application of the sample. The protein loading procedure for all runs was carried out after the gel tubes were in place and the upper buffer solution added. Standardized samples were carefully layered at the gel-buffer interface. Although a serological pipette may be used, a semi-automatic pipetting device (Biopette) was preferred. This device delivers a precise amount of liquid under pressure. A protein load of 330 micrograms per tube was used for general protein gels and 660 micrograms for the enzyme gels. These heavy concentrations were necessary to elucidate the weaker bands.

A standard time of 150 minutes was used. For the first 30 minutes, a reduced amperage (1.25 ma/gel) was applied to allow the protein to migrate into the gel without creating convection currents in the upper buffer. The amperage was then increased to 3.5 ma/gel in runs using tris-glycine or barbituric acid buffer systems and to 2.5 ma/gel for those with tris-borate systems. After the 30 minute adjustment, constant voltage was maintained. Voltage/amperage relationships varied between different buffer and gel systems. Slight differences were detected between runs utilizing the same systems.

Upon completion of a run, the gels were immediately removed from the tubes for staining. Although various removal procedures have been described involving hypodermic needles, water pressure, etc., a thin, stainless steel wire, mounted on one arm of a U shaped frame was found to be most effective in extracting the gels without damage.

With the U frame submerged in a shallow pan of water, the loose end of the wire is carefully threaded through the tube between the gel and the tube wall. With the tube submerged and the wire taut, the tube is rotated against the wire. This frees the gel from the tube wall so that it slips out as the wire is withdrawn.

For all enzyme staining, Brewbaker's formulations and procedures were followed without modification (1968). For general protein, the staining method of Chramback et al (1967) was used. This method employs coomassie brilliant blue as a stain and has certain advantages over the napthol blue black methods. An important advantage is its sensitivity to concentrations of protein. The weak bands in a pattern may develop more clearly without the stronger bands overstaining. Also, destaining is unnecessary, thus eliminating the possibility of "washing out" the weaker bands. However, the method was found to have at least one serious disadvantage. Gels stored in the recommended solution of 10% trichloracetic acid tend to shrink, making delayed evaluations difficult and reevaluation inaccurate after long storage periods (10-12 weeks).

Initially, a recording/integrating densitometer was used for evaluating the stained gels. However, this instrument proved to be unsatisfactory in

defining weaker bands, and the gels were therefore plotted and evaluated visually. Qualitative characteristics of the patterns and the relative electrophoretic mobility of the various bands were of primary interest. Quantitative evaluations were limited to the width and color intensity of the various bands.

PHASE II

In addition to general protein, four enzyme systems were studied: acid phosphatase, leucine amino peptidase, peroxidase, and esterase. Eight trees from a single West Virginia source were used for all systems, but four additional trees were tested for general protein. Two of these trees were from a distinctly separated stand, located so as to eliminate the possibility of cross pollination with other trees in the study.

Two lots of six seeds were selected from each tree. The number of seeds per lot was determined by material requirements for extraction, protein content assay, and the various electrophoretic runs required to investigate all systems. Strict isolation was maintained between seed lots during extraction procedures.

A sample of each extract was loaded into single gel tubes. Twelve gels, representing twelve different seed lots (6 trees), were used in a single electrophoretic run. Two such runs were made for general protein and each enzyme system. This procedure gave two independent observations per seed lot, and a total of four observations per tree for each system.

The methods employed in this study yielded results with little or no variation between replications. However, strict control had to be maintained over all system components and conditions. Slight variations in gel or buffer characteristics had serious effects on the resulting patterns.

Yue (1969) found that the protein concentration was very important for satisfactory isoenzyme elucidation of glutamic dehydrogenase. Concentrations above the optimum range produced blurry patterns, while weaker bands could not be detected if the concentration was too low. Similar results were obtained during this study. Due to the limitations of the methods employed, the possibility that some variation in gel patterns may be a result of differences in protein concentration rather than true variations in protein composition should be recognized.

Fuzzy or blurred banding was characteristic of acid phosphatase gel patterns at all concentrations tested. However, apparent variations within and between trees were confined to quantitative characteristics. The same pattern of one rapid and two slow moving bands was found in all gels (Figure 1). Leucine amino peptidase patterns displayed a similar lack of qualitative variation, both within and between trees. Two narrow, slow moving bands formed the normal pattern of this source (Figure 1).

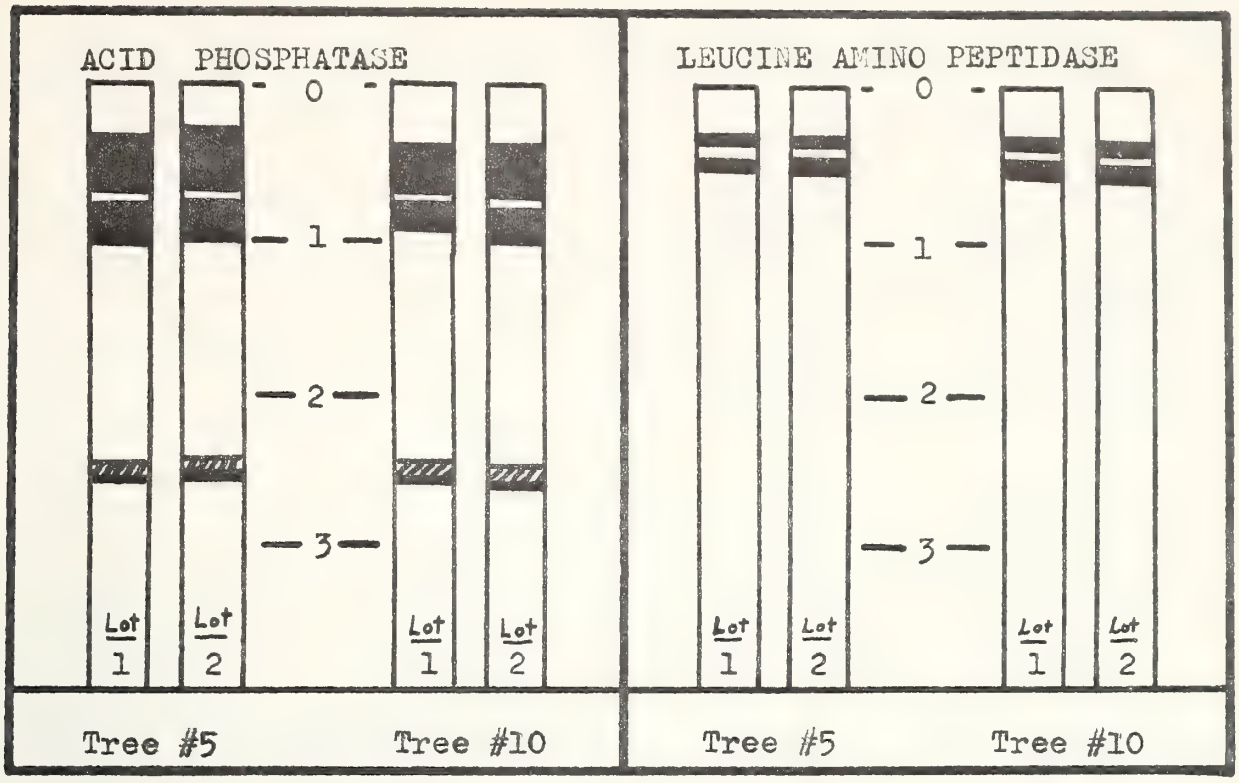

FIGURE #1

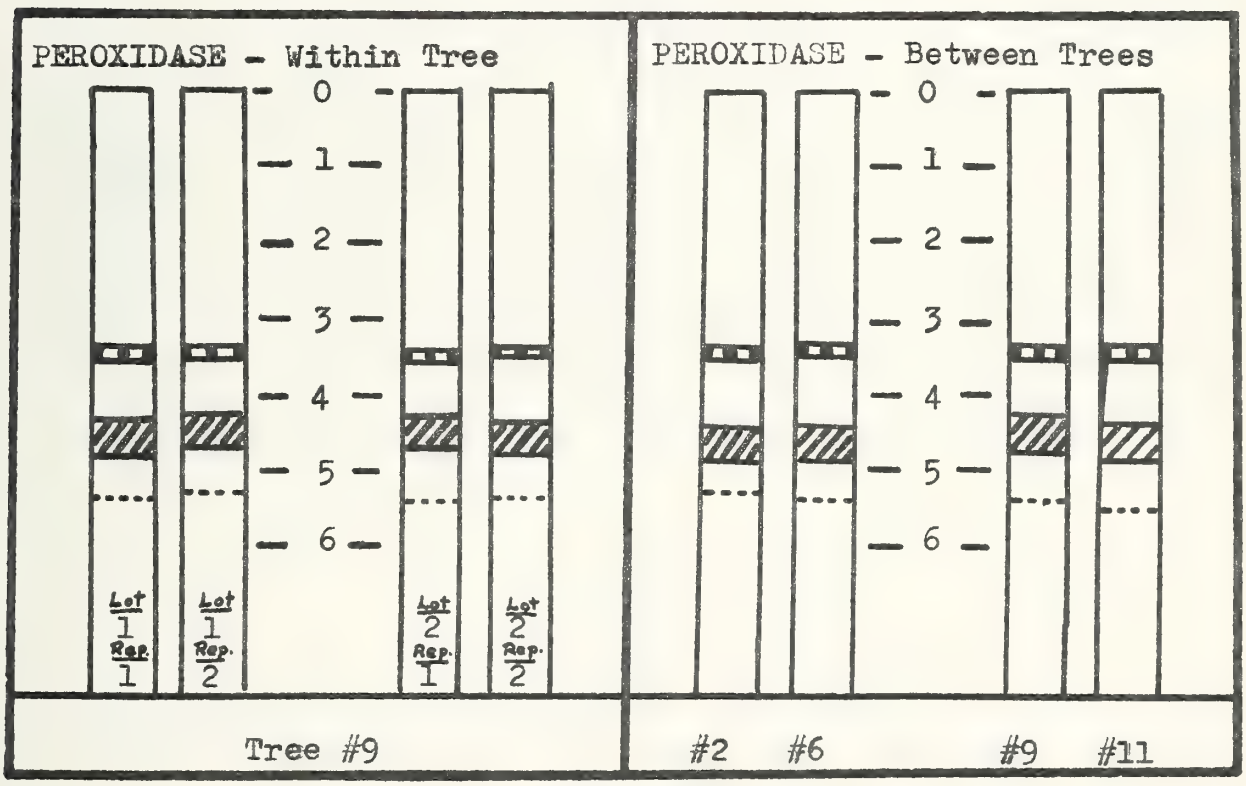

FIGURE #2

Within individual trees, peroxidase gels exhibited a high degree of pattern uniformity. Between trees, only slight variations in apparent quantitative characteristics were evident. The typical banding pattern consisted of two rapidly moving bands, one of which migrated immediately behind the buffer front dye marker and one band of medium mobility. No qualitative pattern differences were detected (Figure 2).

Isoenzyme patterns for esterase were much more variable. Although variations within a tree were normally limited to a single band, multiple banding differences between trees were evident. The basic pattern for this enzyme consisted of one medium width, slow moving band, followed by two narrow bands of slightly lower mobility. A number (0-4) of very slow, narrow bands provided most of the qualitative variability. Some apparent quantitative differences were noted, especially in the fastest moving band (Figure 3).

Due to their non specific and more complex nature, general protein gel patterns displayed more variability than any of the enzyme systems. While differences within trees were confined to one or two bands, differences of three or more bands were normally detected between trees. However, certain bands were found to be present in almost all of the gels, so than an apparent basic pattern for the source was delineated (Figure 4).

Since different gels and buffers were used to elucidate the different enzyme systems, a direct comparison with the general protein pattern was possible with peroxidase only. The fastest moving peroxidase band has the same r.f. as the fastest moving protein band (band 14 in Figure 4). The slowest moving peroxidase band appears to have the same mobility as general protein band 13, and band 13 was not detected on all gels. No general protein band was detected in the area of the middle peroxidase band.

CONCLUSIONS

It appears that there is a high degree of uniformity in acid phosphatase, leucine amino peptidase and peroxidase systems in trees of the West Virginia seed source.

Although esterase and general protein gels displayed numerous qualitative pattern variations, there appears to be a basic set of bands for each of these systems. These basic patterns were found to be stable in most trees tested.

On the basis of pattern resolution, peroxidase, esterase, and general protein were found to be the most promising systems for further study.

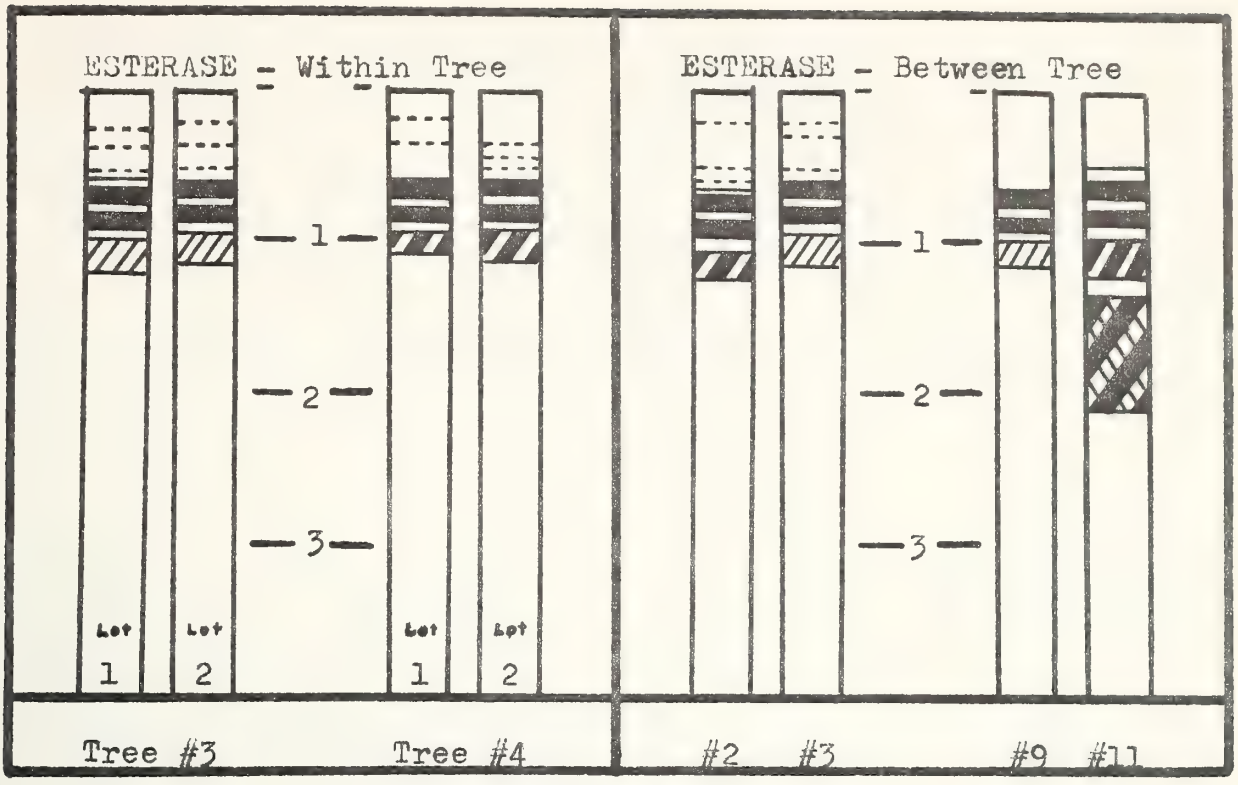

FIGURE #3

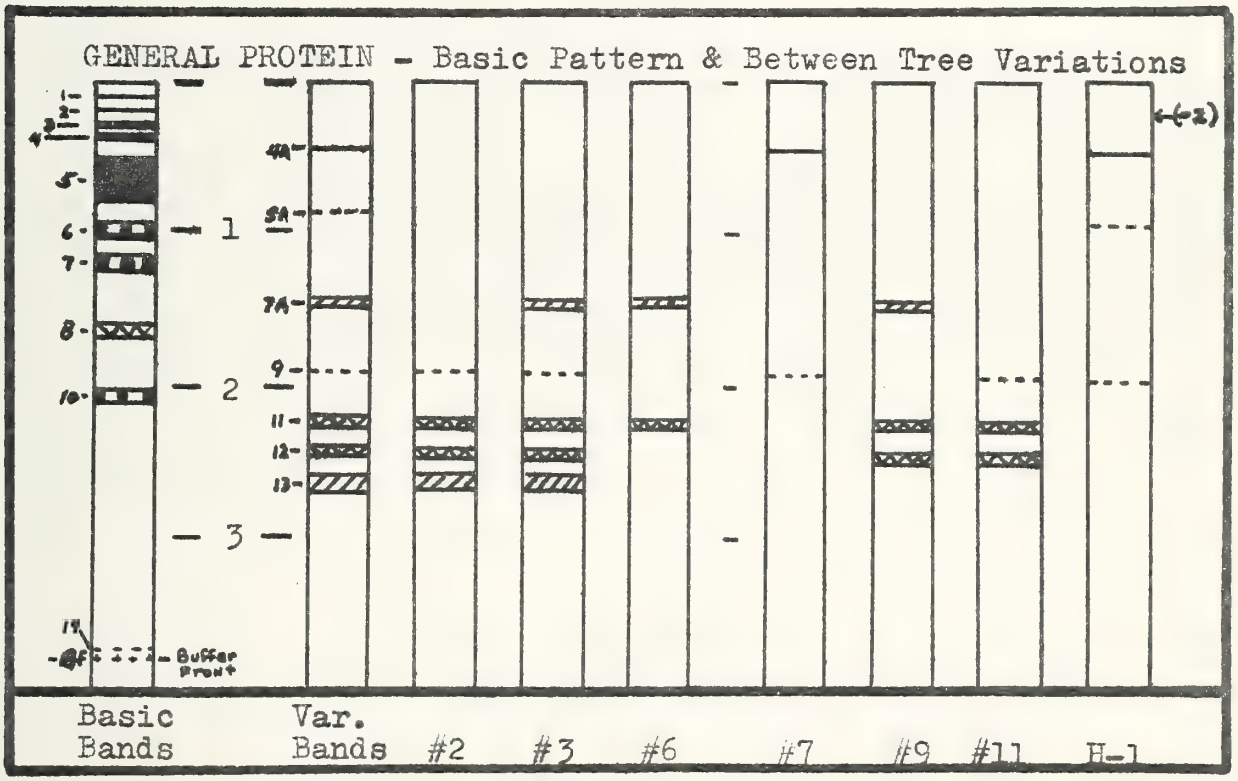

FIGURE #4

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NONOPTIMALITY OF LOCAL RACES

Gene Namkoong[1/]

For many years it was recommended that selection for vegetative vigor be limited to trees naturally grown near their intended planting sites. The assumption was that local genotypes always survive better and are more vigorous than genotypes evolved more distant from the test site. In recent years, however, evidence of the nonoptimality of local sources in many areas has been mounting. One explanation is that natural selection is for rapid reproduction, while tree breeders are concerned with vegetative vigor. This paper outlines some evidence of nonoptimality of local sources and proposes another explanation.

Traditional Theory

Strong support for the theory of optimality of local races was presented by Clausen et al. (1948), who found that local populations of Achillea lanulosa Nutt. are well adapted to local variants in environment. Their model leads to the conclusion that natural selection continually eliminates all migrants and segregants not suited to local environments. Thus, in a wide-ranging species, the homogenizing effects of migration are often overcome, and a series of locally adapted populations evolves on all sites. Regardless of whether a species extends over discrete sites (Fisher 1950; Hanson 1966) or over environmental clines (Langlet 1936), almost any restriction on migration would be expected to produce clines of genotypes reasonably well adapted to local environments. The relative effectiveness of migration rates and selection advantage would determine the strength of clinal variation.

The problem for tree breeders in utilizing any information on natural variation is imperfect correlation between vegetative vigor and rapid reproductive success. The correlation can often be expected to be high among species which normally undergo population reduction due to severe vegetative competition. In such species, early growth rates can be critical to successful reproduction and selection. Thus, Clausen et al. (1948) found in the perennial weed A. lanulosa that the measure of reproductive success could as well have been vegetative vigor as seed set because the two were highly correlated. It was not unreasonable to assume that natural selection in forest tree species has been effective in maximizing vegetative vigor, at least in broad environmental regions. Hence, the recommendation that selection be limited to trees naturally grown near their intended planting sites often seems reasonable (Langlet 1936).

Contrary Evidence

As early as 1962, Jonathan Wright pointed to several exceptions to the general rule that local seed sources are superior. He noted that local provenances

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1/ The author is on the staff of the Institute of Forest Genetics, Southern Forest Experiment Station, USDA Forest Service, Gulfport, Mississippi, and the Genetics Department, North Carolina State University at Raleigh; presently stationed at the University of Chicago.

of Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) in the Pacific Northwest were not optimal in several tests. Since that time, more exceptions have appeared in print. They suggest that a new generalization would better fit the data. In fact, the general concept that static optima generally exist should be reexamined in light of newer theories on evolution in variable environments. Since the environments of species exhibiting racial variation range widely in space and time, such reexamination might suggest new breeding procedures.

Studies too numerous to mention individually have demonstrated the existence of optimal growth provenances of Pinus sylvestris L. and Picea abies (L.) Karst. in northern Europe. In some widely distributed species growing in milder climates, local provenances do not generally grow best outside of ecological zones which seem to provide optimal conditions for high vigor.

For example, evidence is mounting with the age of tests that an optimal growth zone exists for loblolly pine (Pinus taeda L.) along the southeastern border of its range. Wells and Wakeley (1966) find that vigor can be improved up to 10 or 20 percent by moving seed up to 200 miles to the north and west. Their measurements probably are from old enough trees and represent enough yearly variations to reflect a true difference in growth.

On tests with young materials of black walnut (Juglans nigra L.), Bey (1968) found a similar trend; i.e., growth potentials were highest for sources from moderate climates. Also with young materials, Squillace (1966a, 1966b) found that slash pine (Pinus elliottii Engelm.) possesses an ecological development peak in the interior of its range coincident with an optimal combination of climatic factors. Genotypes from this region are more vigorous than local sources in Olustee, Florida.

Probably, tests with ponderosa pine (Pinus ponderosa Laws.) provide the most definitive long-term examples of genotypic sources from optimal ecological zones outgrowing local sources in more marginal areas. In the Northwest, Squillace and Silen (1962) found that races from milder climatic regions had greater growth potentials than those from the harsher environments more inland and at higher elevations. More recently, in California, Conkle (personal communication) has found clear evidence of the existence of an ecologically optimal growth zone in the middle of an elevational gradient. In this zone, where soils are deepest, rainfall distribution is best, and climate is mildest, all seed sources, including the midelevation source, reach their best development. When planted on upper and lower slopes, the midelevation source still consistently grows considerably more vigorously than local genotypes. This pattern was evident at 10 years of age, and at 25 years it is accentuated. A close examination of the data of Clausen et al. (1948) also reveals that for A. lanulosa performance in the high elevation, plants from more moderate elevational climates did better than those from the nearest seed sources.

It is possible that in geographically varying tree species local racial variants from ecologically marginal areas may not be optimal, at least in terms of growth vigor. If it can also be assumed that natural selection among genetic variants is correlated with growth vigor, a nonmaximal growth genotype must also have less than maximal competitive fitness. If a species is evolutionarily successful, some compensatory benefits must accompany the loss of vigor.

Maintaining Vigor Loss

There are probably as many combinations of compensatory factors as there are species. In some cases, the relative loss of vigor may be poorly correlated with reproductive success. This might well be the case when measurements are only taken over a small portion of the life cycle or in a small number of environments. When Scots pine is transplanted over very long distances, temperature and phenological effects make vegetative vigor very poorly correlated with seed set and pollen maturation (Eiche 1966; van Buijtenen and Stern 1967). In tests with young slash pines, transitional climatic cycles may be responsible for the temporary success of nonlocal provenances (Bengtson et al. 1967). However, the prevalence of optimal nonlocal provenances in continuously distributed populations indicates a real and permanent loss of vigor. The large losses of vigor demonstrated in the old materials of local ponderosa pine and loblolly pine provenances also indicate that short-term climatic or other environmental trends do not affect the comparisons.

It is reasonable to expect that, in some cases, vigor is highly correlated with reproductive success and that present forest tree populations in ecologically marginal areas are not maximally fit for their present environment. These populations may be better adapted to more severe environments than those presently available to them. It is clearly better for trees to adapt to present environments and to adjust competition and reproduction for maximum vegetative production. However, since the exact environment of the progeny generation is sensed with high uncertainty in the present generation, errors are to be expected in adjusting the organism. In cases where populations face variable and uncertain environments, a conservative strategy would require good adaptation to poor environments if they are frequent and have a drastic effect on survival.

The question of how populations remain stable under changing environments was considered by Levene (1953). He showed that genetic equilibria can exist if the population is faced with two environments and the alternate alleles partially adapt the genotype to the alternate environments. If the harmonic mean of the loss in fitness caused by possessing the wrong alleles in the wrong environments is less than the arithmetic mean fitness loss, then a stable, optimal, intermediate gene frequency exists. The concept of intermediate, stable, optimal genetic populations evolving under variable environments was considerably extended by Levins (1968), who defined general optimal conditions for stable equilibria. He showed that maximum fitness, when measured over several generations, can be achieved by populations which are not maximally fit in any one environment but are not badly fit for most environmental variations. If future generations face uncertain variations in climatic factors or among soil or elevational gradients, it is advantageous for the population to remain adapted to harsh environments. In tree species--especially for races on ecologically marginal and possibly highly variable sites--it would be advantageous to not respond to selection for what may prove to be transiently favorable site factors. Only in more stable or optimal areas might fine adjustment to environments add to long-term survival of the species.

Since there is some advantage to conservative response to varying environmental factors, some physiological and genetic controls to dampen any overreaction to transient environments may have evolved. However, simpler mechanisms also

exist. Since the lack of optimum adaptation seems strongest in ecologically marginal sites, the conservative responses are most obvious in those sites which are most likely to have most recently been subjected to critical stresses. With some restriction on migration, the local population in a marginal area may maintain a lower fitness for better environments simply by constantly fluctuating. Antonovics (1968) has recently shown that, among perennial organisms, even limited amounts of pollen migration can inhibit response to selection and help maintain unfavorable genes in a population. Thus, constant change and less than maximal immediate fitness in marginal populations may be of long-term value.

CONCLUSIONS

The examples cited indicate that a conservative strategy of ecologically marginal populations is common. The breeder must wonder if he may be more audacious than nature has been and use the greater vigor of ecologically optimal provenances on more marginal sites. What nature considers to be transient site improvements may prove permanent enough for the breeder. An answer can be obtained only through tests of plant materials and observations of environmental patterns of variation.

If the correlation between vigor and reproductive success is high, local provenances may have maximal vigor. However, if vegetative vigor is poorly correlated with natural reproductive success, the breeder should consider provenance selection in regions of optimal ecological development and minimal environmental stress. His requirements for reproduction and timber production are separable.

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PROVENANCE TESTING MEXICAN PINES IN THE UNITED STATES AND BRAZIL [1]

L. C. Saylor [2]

The flora of Mexico, including many forest tree species, is noted for its great diversity. As a result of a wide variety of environmental conditions, selection forces operating for millions of years in combination with frequent hybridization and introgression have created a wealth of inter- and intra-specific variation. In recent years, forest geneticists have recognized the potential value of this material for use in Mexico and other regions where suitable local tree species are lacking. Consequently, several programs have been initiated throughout the world to evaluate and utilize Mexican tree species, especially the pines. [3] One such project involved the N. C. State Industry Tree Improvement Program. [3]

In 1961 several cooperators in the industry program became interested in trying to do something with their problem sites where local species have failed or do poorly. Several methods involving selection, hybridization, and the introduction of exotics were proposed, and various combinations of these were selected for trial by certain of the cooperators. The purpose of this paper is to present early results of the study involving the use of Mexican pines as exotics in southeastern United States, Hawaii, and Brazil.

OBJECTIVES

The original intent was to collect material primarily for trial on problem sites scattered throughout southeastern United States. These areas vary from dry sandy sites to those that are excessively wet, and they range from coastal regions near sea level to the natural hardwood sites of higher elevations. Because of the large quantity of seed actually obtained, however, the study was expanded later to include locations in Brazil belonging to two of the cooperators; material was also made available to the U. S. Forest Service for testing in Hawaii.

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[1] Paper number 2897 of the Journal Series of the North Carolina State University Agricultural Experiment Station, Raleigh

[2] The author is Professor of Genetics and Forestry, School of Forest Resources, N. C. State University, Raleigh

[3] Participants included: Continental Can Company, Inc., Hiwasee Land Company (Bowaters Southern Paper Corp.), Kimberly-Clark Corporation, Union Camp Corporation, U. S. Plywood-Champion Papers, Inc., and Westvaco Corporation.

In addition to the species-site tests, other less applied objectives were incorporated into the original work plan. One of these was to determine the range of variability in wood qualities that existed both within and between species growing in natural stands under different environmental conditions. Material was also collected for use in studying species relationships, including karyological investigations. Results of the wood study have already been reported (Zobel, 1965), while those from the karyological analysis are being incorporated into a larger study of the genus Pinus which is nearing completion.

METHODS

Collections

Considerable time was spent prior to the trip in planning the collection activities, especially in determining the areas and species to be utilized. Although Mexico and the southern regions of the United States differ considerably in latitude, it was felt that certain areas of somewhat comparable environmental conditions existed where altitudinal differences sufficiently modified temperatures and precipitation. It was recognized, of course, that elevation is never a complete substitute for latitude because of day length, intensity of actinic rays, and other complicating factors.

Collection areas were selected in the cold-temperate and warm-temperate climatic zones of the Sierra Madre Occidental, Sierra Madre Oriental and the Great Cross Range according to site conditions and estimated cone crops. Collections were made in 1962 during the months of November and December from a minimum of five trees per species in each stand. Trees of good phenotypes with a minimum of 100 cones were selected, but occasionally trees of inferior form had to be accepted because of the badly cutover condition of some stands in strategic areas. Along with the cones, two 11 mm. increment cores and various samples of vegetative material were obtained from each tree. All material was kept separate for each tree.

Collections were made for 17 species of which 12 had sufficient seed to be included in the provenance tests (Table 1). A wide variety of sites and habitats were sampled from the northern regions of Chihuahua (30^{o} latitude) to south-central Puebla (19^{o} latitude). Elevations ranged from 4,500 to 12,000 feet and soil conditions varied from essentially pure volcanic ash to well developed fertile loams to very poor soils predominantly composed of clay or rock.

Original plans were to have one of the two collection teams concentrate its activities in the northern regions of the Sierra Madre Occidental, but very poor cone crops along with severe insect infestations greatly reduced the collections in these areas. Consequently, the bulk of the seed (approximately 81 percent) was obtained from more southerly areas in the states of Mexico, Puebla and Michoacan. Details of the collection trip can be obtained from the summary by Saylor and McElwee (1963) which includes suggestions for planning and executing such operations.

Nursery Operations

All seeds were extracted in Mexico using a combination of air drying in

Table 1. Summary of cone collections.

	Species [1/]	Number of Trees	Number of Stand Locations	Total Cones
1.	P. montezumae Lamb.	22	5	7,549
2.	P. teocote Schiede & Deppe	10	2	4,857
3.	P. hartwegii Lindl.	5	1	1,200
4.	P. leiophylla Schiede & Deppe	12	3	3,263
5.	P. patula Schiede & Deppe	10	2	3,782
6.	P. rudis Endl.	5	1	1,543
7.	P. pseudostrobus Lindl.	10	2	3,238
8.	P. tenuifolia Benth.	11	2	3,229
9.	P. lawsonii Roezl	10	2	5,899
10.	P. oocarpa Schiede	11	2	2,985
11.	P. michoacana Martinez	18	4	3,314
12.	P. arizonica Engelm.	3	1	523
13.	P. chihuahuana Engelm.	1	1	10
14.	P. herrerai Martinez	1	1	100
15.	P. durangensis Martinez	1	1	36
16.	P. lumholtzii Robins. & Fern.	2	1	8
17.	P. lutea Blanco	1	1	5
		133	32	41,541

[1/] The following quantities of bulk seed of undetermined sources were also obtained: (a) P. michoacana - 1 1/2 lbs.; (b) P. douglasiana Martinez - 1 1/2 lbs.; and (c) P. leiophylla - 1 lb.

the sun and kiln extraction. In 1963 the seeds were sown in nurseries located in Tennessee (Vonore), North Carolina (Lumberton), Alabama (Childersberg), Hawaii, and central and southern Brazil. All seedlings for a given company's test plantings were grown in one nursery to avoid extraneous variation caused by nursery effects.

In general the techniques used in growing the Mexican pines were similar to those used for the southern pines (e.g., loblolly and shortleaf pines) of the United States. However, certain problems were encountered that are worthy of discussion at this time because of the effects they had on the condition of the planting stock.

For some species certain seed lots germinated very poorly, and in one case, P. lawsonii, none of the seeds germinated. The primary cause for this was associated with insect damage, although other undetermined factors are also suspected for P. lawsonii. In at least two nurseries, severe damping-off occurred in several locations; this was eventually controlled with the use of such fungicides as Captan and Hydro-oxyquinoline, but some retardation in development did occur.

Severe cold damage was the most serious problem encountered in the nurseries located in southern United States. The damage varied among species, but all except those from the highest elevations (e.g., P. hartwegii, P. rudis, P. arizonica) were affected to some degree. For example, even in the most southerly location (Alabama), P. oocarpa was completely eradicated and P. michoacana was badly damaged by the first hard freeze in October. The problem is related to an inability of the Mexican pines to go dormant before the severe freezes occur in the fall and to remain dormant during the winter months as do the native pines. In addition to the initial damage, most lots suffered from repeated freezes that alternated with warm periods. Pines native to southeastern United States require at least two weeks of warm weather before breaking dormancy, but Mexican pines break dormancy with 4-5 days of warm weather. Consequently, injury was added to injury and this reduced the overall vigor of the planting stock.

Because it was quite evident that the seedlings in the Tennessee nursery were not going to "harden-off" for the winter, and because the seedlings were in such good condition regarding size and vigor, it was decided to lift during the fall rather than the following spring and to then store the seedlings under refrigeration during the winter. Unfortunately, severe mold problems developed during storage, so most of the seedlings were removed and "heeled-in" in holding beds. Again this combination of circumstances tended to adversely affect the condition of the stock.

In Hawaii problems were encountered with damping-off, wind erosion, rodents, birds, flooded beds, high soil pH levels, lack of suitable mycorrhiza, and transplanting shock. All of these contributed to nursery mortality and reduction in vigor of planting stock. On the other hand, most species developed well in the nurseries in Brazil.

The results of the 1963 nursery operations were such that a high percentage of inferior planting stock was produced for most species. Because of the loss of several species immediately after planting and because of the early poor performance of the planted stock that did live, a supplementary

planting was made in 1966. This material was grown in a nursery in Statesboro, Georgia. Some freeze damage was experienced again, but in general, the seedlings obtained from this nursery were quite good.

It is important to recognize that the native pines (loblolly, longleaf, shortleaf and virginia pines) used as checks in the plantings in southern United States were in better condition than much of the Mexican stock at the time of planting. This influenced the early performance and must be considered in evaluating the results.

Planting Design

The same basic pattern, a randomized block design, was used by all participants. In 1964 at least two plantings were established by all but two cooperators. Each planting consisted of four Blocks which were divided into Species Groups which in turn were divided into as many Plots as there were mother trees (families). Two species checks were randomly placed in each Block. Row Plots of 15 seedlings were established using a 9 ft. x 9 ft. spacing. When material was available, border trees were planted completely around each Species Group extending the rows to 17 trees.

Planting Sites

On the United States mainland, plantings were established over a wide variety of sites in West Virginia, North Carolina, Georgia, Florida, Alabama, and Louisiana. Site conditions ranged from excessively wet to very dry, from low elevations near the coast to higher elevations (3,000 feet) in the mountains, and from soils high in organic content to those that are mostly sand. In one instance a planting area was selected because it provided especially good conditions to test resistance to Fomes annosus. Site preparation varied from minimal operations using only burning to those involving maximum preparation by discing and harrowing. Most of the planting was done by hand.

For the Hawaiian operation, plantings were established on the islands of Maui and Molokai at elevations of 3,200 and 6,000 feet, respectively. The areas were previously covered with grass and/or shrubs, and the soils consist of deep loams (Maui) and silty clays (Molokai). Rainfall averages 40-50 inches annually in these areas.

In Brazil, plantings were located on two very different sites. U. S. Plywood-Champion, Inc. selected an area in the state of Sao Paulo with well drained, sandy soil that was sparsely covered with scrub vegetation prior to planting. Although freezing temperatures do not occur in this area, severe winter droughts are common. The second area, developed by Westvaco Corporation (Rigesa), is a bottomland site located in the state of Parana. The soil is a fertile, silt loam that historically had been covered with dense vegetation. Rainfall (approximately 60 inches annually) occurs uniformly throughout the year; light frost does occur in this area.

RESULTS

United States Mainland

Initial survival rates of the Mexican pines determined one to six months after planting ranged from approximately 30 to 50 percent for the plantings that were measured. In comparison, results for the native species included as checks averaged 80-100 percent.

Considerable variation in survival occurred among species and between locations. For example, early survival for three species (P. leiophylla, P. patula, and P. pseudostrobus) in one block of a planting in the mountains of West Virginia was above 90 percent, while it was only 22 percent for P. teocote in the same block; across three of the blocks, survival varied from 15 to 100 percent for P. leiophylla. In contrasting areas, one planting in the Cumberland Plateau with somewhat similar conditions to those for the West Virginia planting had an initial survival rate of less than 10 percent; this was rather suprising because only species with some known tolerance to low temperature were selected for this planting.

At the end of one complete year in the field, survival rates dropped to less than 12 percent for the plantings that were sampled; slightly higher rates possibly occurred in a few areas that were only spot checked. By the end of two years, performance was so poor that essentially all plantings were abandoned as failures. Certainly in overall performance (i.e., survival and height growth) the Mexican pines were quite inferior to the native species checks. Even when special attempts were made to preserve individual species for demonstration purposes, most Mexican pines failed to survive.

Hawaii

The performance of the Mexican pines on both islands was considerably better than that on the mainland. Growth after three years in the field (Table 2) was good enough for 8 of the 12 species tested to indicate that there may be some potential value for a few of them. Two other species (P. rudis and P. hartwegii) have grass stages and thus cannot be properly evaluated in such a short time; because these two species had the highest survival of any species on the island of Maui, they also may be of value. These species also survived better than the others on the mainland, but growth was so slow they were suppressed by the natural vegetation.

Although survival in general was disappointing in that half of the species had a survival rate lower than 33 percent at the end of the third growing season, the pattern of mortality indicates these data may be misleading. Most of the mortality took place within eight months of planting; differences between the first and third year measurements were eight percent or less for every species. This suggests that either poor planting stock or poor planting conditions or both may have affected the initial performance of these species so adversely that a meaningful evaluation cannot be made without making additional tests.

Brazil

The plantings in Brazil were unquestionably the most successful of any of

Table 2. Survival and height measurements of three year old plantings in Hawaii.[1/]

Species	Island of Maui[2/]				Island of Molokai[2/]			
	No. of Families[3/]	Height (ft.)		Survival (%)		No. of Families	Height (ft.)		Survival (%)	
		Species Average	Family Range	Species Average	Family Range		Species Average	Family Range	Species Average	Family Range
P. patula	7	6.5	5.0-7.5	24	20-27					
P. tenuifolia	4	6.5	5.5-8.0	21	15-30	2	5.5	5.5-6.5	72	33-82
P. pseudostrobus	10	6.0	4.0-7.0	29	22-47	8	6.0	4.0-7.0	31	7-47
P. montezumae var. macrocarpa	1	5.5		18						
P. leiophylla	9	3.5	3.0-4.5	48	27-70	6	5.0	4.0-6.0	63	36-85
P. teocote	4	3.5	3.0-4.5	39	18-57					
P. montezumae	13	3.5	2.0-4.5	18	0-44	7	3.0	1.5-3.5	14	0-31
P. michoacana var. cornuta	9	3.0	2.0-4.0	22	7-38	5	4.5	2.5-7.0	25	10-42
P. michoacana	3	2.5	2.0-3.5	11	5-23					
P. rudis	3	2.5	2.5-3.0	62	50-70					
P. hartwegii	2	2.0		65	63-67					
P. oocarpa	5	2.0	1.5-2.0	20	13-23					

1/ Data supplied by Craig Whitesell, U. S. Forest Service, Honolulu, Hawaii.

2/ Each planting is composed of four replications (Blocks).

3/ 14 or 15 open pollinated progeny were planted for each family in all replications.

the 20 that were established. Survival was outstanding in the state of Parana with eight out of nine species having survival rates of 80 percent or greater (Table 3). On the more droughty sites in Sao Paulo, survival was somewhat poorer, ranging from 6 to 79 percent; 7 of the 11 species had rates greater than 50 percent (Table 4).

Considerable variation in growth occurred between species in both locations. Third year height measurements ranged from 4 to 14 feet in Sao Paulo and from 0.5 to 12 feet in Parana; more than half of the species tested had growth rates of two feet per year or greater. As in Hawaii, P. patula was the most outstanding species in both areas; the freezing temperatures in Parana appeared to be no problem because the plants apparently were dormant when they occurred.

The plantings in Sao Paulo were the only ones other than those on the United States mainland in which non-Mexican pines were included as species checks. In this case P. elliottii and P. taeda were used, and both were appreciably better than any of the Mexican pines (except perhaps P. patula) when both growth rate and survival are combined (Table 4). These results are in close agreement with those from other plantations of pines from southeastern United States that have been established in Brazil.

DISCUSSION AND CONCLUSIONS

Much of the material planted in southeastern United States was established with guarded optimism, because it was felt that differences in environmental conditions between the test sites and the collection sites were too great. However, complete failure of all species within two years was not anticipated; undoubtedly the poor condition of much of the planting stock was an important cause of this early mortality. The single most important factor influencing mortality and growth was associated with freeze damage. Injury by freezing was repeatedly inflicted on the seedlings of most species, including several that are known to withstand quite low temperatures in their native habitat. The problem was associated with an inability to become dormant before freezing temperatures occur in the fall and to remain dormant during the winter. On the other hand, the few species that were not damaged by the cold weather did appear to be affected adversely by the high summer temperatures.

Because these results are so similar to those reported by Zobel (1969) in areas throughout the South, it appears that most Mexican pines have very limited value, if any, for commercial use in the southern and southeastern regions of the United States. Without question, if they are to be used, very detailed information on growth patterns, site conditions, environmental stress factors, etc. will have to be obtained to permit the selection of species or strains better adapted to this part of the world.

In both Hawaii and Brazil, the growth and survival data are impressive enough to indicate that some species of Mexican pines may have value as a source of coniferous wood needed so badly in these areas. Although not greatly superior to other pines being tested (e.g., P. elliottii and P. taeda), species such as P. patula, P. leiophylla, P. pseudostrobus, P. tenuifolia, and P. oocarpa have certainly done well enough to warrant further

Table 3. Survival and height measurements of a three year old planting in Parana, Brazil.[1/]

Species	No. of Families[2/]	Height (ft.)		Survival (%)	
		Species Average	Family Range	Species Average	Family Range
P. patula	5	12.0	10.0-13.5	98	93-100
P. leiophylla	7	12.0	10.0-14.0	99	98-100
P. oocarpa	3	12.0	11.0-13.5	98	93-100
P. pseudostrobus	7	6.5	5.0-7.5	99	98-100
P. tenuifolia	2	6.0	5.5-6.5	100	
P. michoacana	3	4.0	3.0-4.5	99	97-100
P. michoacana var. cornuta	4	4.0	3.0-5.0	99	97-100
P. montezumae	7	2.0	1.5-2.0	80	65-90
P. rudis	2	0.5	0.5-1.0	58	55-61

1/ The data were provided through the courtesy of Westvaco Corporation; the planting was composed of four replications (Blocks).

2/ Fifteen open pollinated progeny were planted for each family in all replications.

Table 4. Survival and height measurements of three year old plantings in Sao Paulo, Brazil.[1/]

Species	Planting I [2/]				Planting II [2/]				
	No. of Families[3/]	Height (ft.) Family Average	Height (ft.) Range	Survival (%) Family Average	Survival (%) Range	No. of Families	Height (ft.) Family Average	Height (ft.) Range	Survival (%) Family Average	Survival (%) Range
P. patula	4	14.0	13.5-15.0	72	68-88	2	14.0	13.5-14.0	63	57-68
P. leiophylla	9	9.0	7.0-10.0	76	65-87	8	10.5	10.0-12.5	79	59-94
P. pseudostrobus	7	7.5	3.0-9.5	79	72-85	7	8.5	3.5-10.0	77	65-87
P. teocote	6	7.0	6.0-8.0	52	20-82					
P. douglasiana[4/]		7.0		38			9.5		48	
P. tenuifolia	2	6.0	5.5-7.0	81	70-91	1	7.0		73	
P. durangensis	2	4.5	4.0-5.0	72	59-84					
P. michoacana	13	4.0	3.0-6.5	48	15-73	7	4.0	3.5-5.0	41	20-87
P. montezumae	11	4.0	3.5-5.0	53	23-82	8	4.0	3.5-5.0	33	3-59
P. oocarpa	5	4.0	3.0-5.0	17	5-38	2	8.0	8.0-8.5	50	48-51
P. hartwegii	2	4.0	1.5-6.0	6	3-9					
P. taeda[4/]		11.5		95			12.0		94	
P. elliottii[4/]		10.0		82			10.5		92	

1/ The data were provided through the courtesy of U. S. Plywood-Champion Papers, Inc.; values are determined from plot means of individual families.

2/ Each planting is composed of four replications (Blocks).

3/ Fifteen open pollinated progeny were planted for each family in all replications.

4/ Seeds used were from a commercial seed lot.

evaluation. However, because the results are so variable, any large scale introduction should be done cautiously until further assessments are made. Again great care should be exercised in selecting any material to be established.

In many ways the results in Brazil are comparable to those found in other regions of the Southern Hemisphere. For example, in their review of forest tree introduction in Rhodesia, Barrett and Mullin (1968) noted that at least 11 of 21 species of Mexican pines being tested were worthy of further consideration and study. Approximately 44 percent of the 36 pines being tested showed some promise; interestingly, three of the most impressive species (P. patula, P. elliottii, and P. khasya) come from quite disjunct areas. In all cases, but especially the Mexican pines, the importance of proper seed source was emphasized.

The results of this study as well as those from several others underscore problems associated with provenance testing in general that are especially critical when working with the Mexican pines. The most important of these involves properly matching seed source and potential planting site to provide the greatest possible chance for success; in the present study this was improperly done in several areas and consequently this was a major cause of failure. Because conditions (e.g., temperature, moisture, soil, etc.) in many areas of Mexico vary considerably within short distances, it seems imperative that some system using climatic analogues be employed. This will not ensure success, because it is difficult to predict such things as changes in growth cycles, and it is still difficult to get accurate data for some areas in Mexico. It is important, however, if for no other reason than to force a critical evaluation and comparison of important environmental factors.

Another important problem common in Mexico involves proper delineation of species. The extent of natural variation is poorly known for most species, although it is generally recognized that many of them are extremely variable as a result of strong selection pressures and frequent hybridization; this has created populations in many areas that are extremely difficult to identify taxonomically.

It is apparent, therefore, that if the potential of the Mexican pines in plant introduction is to be fully realized in the future, considerable effort must be expended to strengthen our knowledge of the biology, ecology, and taxonomy of this group of species.

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EARLY EVALUATION OF A SEED SOURCE STUDY IN EASTERN REDCEDAR (JUNIPERUS VIRGINIANA L.) IN SOUTH CAROLINA[1/]

Roland E. Schoenike[2/]

Eastern redcedar is an important and widespread coniferous species occurring throughout the eastern half of the United States (exclusive of south Florida) and in southern Canada. The climatic conditions that prevail over this large area are reflective of the great adaptability of this species and include a growing season variability ranging from 120 days in the northwest to 250 days or more in the southeast, and precipitation extremes from 16 to more than 60 inches annually. Nor are the soils on which it grows any less variable, since it does occur on dry rock outcrops, deep alluvial soils, limestone bluffs, heavy clays and swampy ground, with pH ranges of 4.7 to 7.8 (Williamson, 1957, U. S. Forest Service, 1965).

As in other wide-ranging species, eastern redcedar displays a great deal of variation, particularly in such characteristics as crown form, amount of scale foliage, and growth. Crown form was studied by Fernald and Griscom (1935) who were able to distinguish a northern race which they named Juniperus virginiana var. crebra. This variety, conspicuous with its slender, columnar, or narrowly-pyramidal crown form, was said to grow in the northeastern states south as far as Virginia, and westward to Illinois and Iowa. The broader-crown form, occurring mainly in the southern states, was considered more typical of the species as a whole. Fassett's (1943) study corroborated the work of Fernald and Griscom as far as the northeastern and southern states were concerned, but he was unable to apply varietal distinctions to the midwestern trees. Moreover, he was unable to confirm that the variety crebra could be distinguished by the shape of the scale leaves or the pitting of the seeds as reported by the New England observers. Since 1943 foresters in different parts of the South have noted that the columnar habit type of growth occurs commonly in redcedar in many areas, sometimes alone, but more often mixed with broad-crown trees. The validity of variety crebra as a taxonomic entity must, at this time, be questioned. It would seem to be better regarded as a habit type and given the designation forma.[3/]

More common than broadly defined geographic races has been the variation observed among individual trees. In South Carolina at least six habit types can be found (personal observation). Horticulturists have long known of the

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[2/] The author is Associate Professor, Department of Forestry, Clemson University, Clemson, S. C.

[3/] The designation forma is used in taxonomic literature for a more or less constant character that is not geographically defined.

species' variability and have taken advantage of numerous crown forms, foliage type, and foliage color variants to produce cultivars having ornamental value. A perusal of several taxonomic and horticultural tree manuals shows that Bailey (1933) lists 28 cultivars; Rehder (1940) describes 18; Krussman (1960) recognizes 31; Wyman (1965) lists 23 of which 13 were recommended for ornamental use; Dallimore and Jackson (1966) give 21; and Den Ouden and Boom (1966) recognize 61 of which 45 are still in cultivation. In a recent issue of the American Nurseryman (May 15, 1969) a Tennessee nurseryman claims to have 221 cultivars of Juniperus spp. under test, many of which are J. virginiana.

Winter foliage color in eastern redcedar was studied by McDermott and Fletcher (1955) in Missouri. These workers reported that the color variation found was due primarily to the amount of exposure to sunlight that the trees were subjected to, the red and purplish colors, in particular, being found on completely exposed trees, whereas green and blue colors were found mainly on shaded trees. They did not rule out the possibility that particular genotypes were more color-susceptible (as a result of anthocyanin production) than others, but believed that the amount of sunlight falling on the leaves was more important than either mineral nutrition or genetic factors in causing color variations in this species.

In an attempt to learn more of racial variation in eastern redcedar, the Central States Experiment Station in 1951 established on the Kaskaskia Experimental Forest near Carbondale, Illinois, a seed source study involving eight provenances. A report on this plantation, six years after planting, was made by Minckler and Ryker (1959). At eight years of age, crown form varied from bushy (broadly conical) to slender (almost cylindrical). Tree height-crown diameter ratios ranged from 3.1 (broad) to 4.1 (slender) among the eight sources. Pronounced differences were also noted for winter foliage color, leaf form, and susceptibility to cedar gall rust (Gymnosporanguim sp.). The authors believed that the major variations were characteristics of the population from which the seed sources were obtained since within a seed source plot relative uniformity was exhibited.

MATERIALS AND METHODS

In 1965 correspondence was initiated with 25 state, federal, and private forestry organizations and six privately-operated nurseries in an attempt to obtain known provenances of eastern redcedar seedling stock. As a result 21 seed source lots were obtained from 13 forestry agencies and nurseries in 13 eastern, southern, and midwestern states (Table 1). Of the 21 seed source lots, eighteen were grown in state nurseries and three were native wildlings dug from pastures and old fields. Eight seed source lots were obtained from one Illinois state nursery. Seedlings were shipped to the Clemson Department of Forestry over a period extending from January 1965 to January 1966. From six nurseries, two shipments were made, each at the end of two successive growing seasons. This was necessary to obtain the desired number of seedlings (approximately 200) from each seed source. The source of seed was traced from nursery records as far as possible. In some cases the state where

Table 1. Seed Source Data on Eastern Redcedar in Clemson, S. C. Plantation

Name of Source	Nursery where raised	Source of seed	Age of Stock	Date received
1. South Dakota	Mason State Tree Nursery, Topeka	South Dakota	a) 2-0 b) 2-0	a) May 1965 b) Nov. 1965
2. Minnesota	Mason State Tree Nursery, Topeka	Minnesota	2-0	May 1965
3. Wisconsin	Mason State Tree Nursery, Topeka	Wisconsin	2-0	May 1965
4. New York	None, wildlings collected	Vicinity of Canton	2-5 yrs.	May 1965
5. Connecticut	None, wildlings collected	Vicinity of North Windham	2-5 yrs.	April 1965
6. Mason, Illinois	Mason State Tree Nursery, Topeka	Mason, Illinois	2-0	May 1965
7. Union County, Ill.	Mason State Tree Nursery, Topeka	Union Co., Ill.	2-0	May 1965
8. Iowa	Iowa State Forest Nursery, Ames	Windbreak trees, Ames vicinity	1-0	Jan. 1966
9. West Virginia	None, wildlings collected	Vicinity of Lakin	2-5 yrs.	a) Jan. 1965 b) Jan. 1966
10. Virginia	Dept. of Conservation, Charlottesville	Virginia	1-0	Jan. 1965
11. Kentucky	Mason State Tree Nursery, Topeka	Kentucky	a) 2-0 b) 2-0	a) May 1965 b) Nov. 1965
12. Dixon Springs, Illinois	Mason State Tree Nursery, Topeka	Dixon Springs, Ill.	a) 2-0 b) 2-0	a) May 1965 b) Nov. 1965
13. Nebraska	Bessey Nursery (U.S.F.S.), Halsey	Vicinity of Anselmo	1-0	May 1965
14. Oklahoma	Oklahoma State Forest Nursery, Washington	Logan County, N. of Cimarron River	a) 2-0 b) 1-0	a) Jan. 1965 b) Jan. 1966
15. Missouri	George White Nursery, Licking	Not known	2-0	Jan. 1965
16. Tennessee	Mason State Tree Nursery, Topeka	Tennessee	a) 2-0 b) 2-0	a) May 1965 b) Nov. 1965
17. North Carolina (Piedmont)	Clayton State Forest Nursery, Clayton	Piedmont of N. C.	1-0	Jan. 1965
18. Mississippi	Waynesboro State Nursery, Waynesboro	Not known	1-0	Jan. 1965
19. Alabama	Olustee State Nursery, Olustee, Fla.	Dallas County	1-0	Jan. 1965
20. South Carolina (Piedmont)	Piedmont Nursery, Pickens	Spartanburg County	1-0	Jan. 1965
21. South Carolina (Coastal)	Piedmont Nursery, Pickens	Vicinity of Georgetown	1-0	Jan. 1965

collections were made was known. In other cases, the county or locality was given. In the case of one source (Mason, Illinois) the seed was obtained from an individual tree.

In summary, neither the method of collection nor the type of material was ideal. However, it was possible in this way to obtain a wide variety of sources more easily and cheaply than by any other method. Sources represented did sample the extremes of the range including Minnesota and New York in the North, South Dakota and Oklahoma in the West, and Mississippi and South Carolina in the South. Seed source information is summarized in Table 1.

All material received was transplanted into nursery beds of the Piedmont Nursery, South Carolina State Commission of Forestry, and grown for one year before being removed to the planting site. The latter was located on the Clemson Forest (Mill Division, Compartment 4) five miles southeast of Clemson. The area was an old field covered with broom sedge (Andropogon spp.) and a variety of other grasses and herbs, and in which a few seedling shortleaf (Pinus echinata) and Virginia (Pinus virginiana) pines and cedars were becoming established. Redcedar occurs commonly in this area. The soil type is classed as a Cecil clay loam, and much of the topsoil had been removed by erosion as a result of past farming practices. Volunteer trees were removed from the area and it was disked three months prior to planting.

The planting design was a randomized block with four replications. Plot size was 25 trees arranged in a 5 x 5 square. Spacing was 5 x 5 feet. The first planting was made in December 1966. In October 1966 a survival count was made and the amount of stock required to replace the seedlings which died during 1965 was tallied. Except for two seed sources (South Carolina coastal and Connecticut) there was sufficient stock in the nursery to replace the dead and missing seedlings. In addition one new seed source lot (Iowa) was planted for the first time. The replacement seedlings were planted in December 1966. No additional seedlings have been planted since this date. The planting site was mowed in September 1967 and in September 1968. No other cultural treatments have been made.

MEASUREMENTS

The first measurements were made in March 1969, three growing seasons after the first trees were planted. Data taken included survival, total height, evidence of disease, winter foliage color, foliage density, and proportion of juvenile foliage. The seedlings were too small to show a trend toward a definite crown form, hence this characteristic was not evaluated.

Two types of disease symptoms were recorded, i.e., presence of cedar galls, and foliage dieback. The symptoms were taken as evidence of Cedar apple rust (Gymnosporangium juniperi-virginianae) and Phomopsis blight (Phomopsis juniperovora) although other leaf diseases might also be involved. Winter foliage color varies considerably from tree to tree and source to source. Four colors were recognized, i.e., green, green-red, purple-red, and red-brown. Foliage density was simply tallied as light,

medium, and heavy, by ocular judgment. Juvenile foliage (awl-shaped, sharp-pointed leaves) was estimated by four, 25 percent classes, i.e., 0-25%, 26-50%, 51-75%, and 76-100%. The results of these measurements are summarized in Tables 2 and 3.

DISCUSSION

Survival. Survival was generally excellent, ranging from 81 to 97 percent except for the Connecticut and Iowa sources in which it was only 55 percent. The Iowa source in particular was heavily attacked by Phomopsis blight and many seedlings were lost. This measure is, however, not significant since first year deaths were largely replanted with nursery replacement stock as described above. It is concluded that initial survival of eastern redcedar is not a problem on suitable sites in the South Carolina Piedmont from whatever seed source the plants are derived as long as they are healthy and vigorous.

Total height. Age at the time of measurement was not constant but varied from four to six years for nursery grown seedlings and probably from four to nine years for wildling stock. Offsetting the age factor, however, are the effects of several transplantings, the shock being much greater for the larger plants. Hence, although a statistical comparison is not valid, a comparison of the average heights still shows several interesting and perhaps significant trends. There were three seed sources, i.e., South Carolina Piedmont, North Carolina, and Virginia, which averaged over four feet in height. These are most certainly the three whose natural habitat coincides most closely with the planting locality. Ten sources averaged between three and four feet in height. This included the remaining southern sources, several from the midwest, and the one from New York. The far west, several midwest, the northern-most and the northeastern-most sources averaged less than three feet in height. The Connecticut source was much the smallest after four years although the stock (wildlings) were among the oldest represented in the plantation.

Disease. Cedar-gall rust infection was generally low and without a pattern among the various seed sources. Most infection occurred on stock originating in Mississippi (13%), Minnesota (10%), and Oklahoma (12%). South Carolina sources were intermediate (8% and 5%). The two northeastern sources had virtually no infection although seven other sources also showed less than three percent infection. Cedar galls are hard to detect when very small, and it will be several years before data taken on this disease will become meaningful for the plantation. Foliage diseases[4/], of which Phomopsis is the most important, are serious on eastern redcedar and were responsible for most mortality in the first two years and even now account for the poor vigor of many plants and sources. Oklahoma, Alabama, Iowa, and Kentucky

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4/ Other leaf diseases including Monochaetia and Cercospora have been reported on junipers. These are not distinguished here from Phomopsis and all are considered simply as leaf diseases.

Table 2. Survival, growth, and disease characteristics of progeny from 21 redcedar seed sources two and three years after planting.

Seed Source	Trees Planted and Survival			Age of Stock	Average Height	Disease Symptoms		
	Blocks	Trees	Survival Percentage	Years	Feet	Cedar Gall	Foliage Disease	Disease-free
						Percentage		
1. South Dakota	4	100	96	5-6	2.84	1	44	55
2. Minnesota	4	100	87	6	2.95	10	62	33
3. Wisconsin	4	100	95	6	3.68	2	59	39
4. New York	4	100	97	6-9	3.17	1	28	72
5. Connecticut	2	50	54	6-9	2.14	0	7	93
6. Mason-Illinois	3	75	89	6	2.61	3	62	37
7. Union Co.-Ill.	4	100	92	6	3.15	1	34	66
8. Iowa	4	100	55	4	2.56	2	60	40
9. West Virginia	4	100	96	5-9	3.85	4	62	37
10. Virginia	4	100	96	5	4.42	4	21	75
11. Kentucky	4	100	97	5-6	2.84	2	75	23
12. Dixon Springs-Illinois	4	100	93	5-6	3.23	0	45	55
13. Nebraska	4	100	93	5	2.81	7	62	41
14. Oklahoma	4	100	89	4-6	2.96	12	77	19
15. Missouri	4	100	90	6	3.66	6	50	47
16. Tennessee	4	100	96	5-6	3.38	2	40	60
17. North Carolina (Piedmont)	4	100	94	5	4.72	1	31	69
18. Mississippi	4	100	94	5	3.93	13	53	37
19. Alabama	4	100	94	5	3.85	6	68	31
20. South Carolina (Piedmont)	4	100	94	5	4.11	5	27	69
21. South Carolina (Coastal)	3	75	81	5	3.24	8	44	53

Table 3. Evaluation of progeny from 21 redcedar seed sources for winter foliage color, foliage density, and amount of juvenile foliage, two and three years after planting.

Seed Source	Winter Foliage Color				Foliage Density			Juvenile Foliage			
	Green	Green-Red	Red-Purple	Red-Brown	Light	Medium	Heavy	0-25	26-50	51-75	76-100
	Percentage				Percentage			Percentage			
1. South Dakota	1	85	7	7	9	76	15	23	39	22	16
2. Minnesota	0	47	39	14	2	75	23	24	32	30	14
3. Wisconsin	2	80	10	2	5	79	16	47	34	13	6
4. New York	0	38	29	33	1	77	22	27	25	28	20
5. Connecticut	0	11	56	33	0	74	26	19	26	18	37
6. Mason, Illinois	0	13	34	53	4	72	24	0	12	30	58
7. Union County, Illinois	1	65	15	19	5	74	21	35	30	21	14
8. Iowa	0	55	25	20	2	84	14	9	29	25	37
9. West Virginia	0	64	5	31	3	73	24	43	30	17	10
10. Virginia	2	71	18	9	11	81	8	15	41	30	14
11. Kentucky	0	68	11	21	14	62	24	9	36	34	21
12. Dixon Springs, Illinois	4	82	8	6	3	84	13	16	30	37	17
13. Nebraska	5	66	19	10	10	70	20	10	13	29	48
14. Oklahoma	12	80	7	1	1	66	33	24	21	25	30
15. Missouri	0	71	17	12	2	78	20	29	30	26	15
16. Tennessee	0	76	14	10	10	74	16	28	33	21	18
17. North Carolina Piedmont	8	80	7	5	17	77	6	26	39	28	7
18. Mississippi	4	63	19	14	7	78	15	14	22	37	27
19. Alabama	9	78	11	2	5	64	31	34	27	20	19
20. South Carolina Piedmont	7	77	6	10	6	78	16	66	24	7	3
21. South Carolina Coastal	3	62	25	10	21	69	10	8	26	28	38

stock show serious leaf disease on 68 to 77 percent of the plants. Virginia, North Carolina and South Carolina stock rated among the least infected. The lowest rate of infection, by far, was shown by the Connecticut source, on which 93 percent of the plants were rated as disease-free. Other sources were intermediate. Since this disease is primarily a nursery disease, the pattern shown may be more indicative of stock infection before planting; however, the health and vigor of the three South Atlantic sources seem to result largely from good general adaptability.

Winter foliage color. Green winter color was most pronounced in the Oklahoma source but even here only 12 percent of the trees were rated green. Green-red or rusty-green accounted for the largest proportion of seedlings in all but two sources. In one of these--the Connecticut source, red-purple foliage color predominated, and in the Mason, Illinois (single tree) source, most of the seedlings were red-brown. Other sources showing a high degree of purplish or red-brown winter foliage included those from Minnesota, New York, and Iowa. Although northern sources generally had more trees showing these colors than did southern sources, there were a number of exceptions. For example, the Wisconsin source had only 12 percent of its trees in these two color classes whereas the South Carolina coastal (southernmost source) had 35 percent.

Foliage Density. The medium foliage density class predominated in all sources, the lowest value being 62 percent (Kentucky source) and the highest, 84 percent (Iowa and Dixon Springs, Illinois sources). Sources with relatively high proportion of trees in the light foliage density class included South Carolina Coastal and North Carolina. Those with low proportion of such trees included the Connecticut and New York sources. Seedlings in the heavy foliage density class were most common in the Oklahoma and Alabama sources.

Juvenile Foliage. The prickly, awl-shaped juvenile leaves persist longer on some trees and sources than on others. This character varied tremendously among the sources. The proportion of trees having juvenile foliage in the 0-25% class ranged from zero to 66 percent. No pattern among the seed sources was apparent and it is quite probable that this is a character more of individual progenies (as the Mason source would indicate) than a reflection of the source. Sources with a high proportion of juvenile foliage included the Mason, Illinois, Nebraska, and South Carolina Coastal sources. Low proportions of juvenile foliage were found in the South Carolina Piedmont, North Carolina, and Wisconsin sources.

CONCLUSIONS

These data are very preliminary since they represent trees that are only four to nine years of age. Therefore, all conclusions must be considered as tentative. Nevertheless, some of these are quite interesting and are set forth here.

1. The three sources representing South Carolina Piedmont, North Carolina Piedmont, and Virginia rate high in survival, total

height, and freedom from disease. They seem to have the best general adaptability to South Carolina Piedmont conditions.

2. Initial survival of all sources is satisfactory. This will be of importance to Christmas tree growers and horticulturists, although it would probably be of somewhat less significance to foresters.

3. Several striking characteristics shown by the Mason, Illinois, single tree source suggests that many characters are under strong genetic control and can be transmitted to their progeny. These include winter foliage color, and proportion of juvenile foliage. The lack of pattern that these characters show with respect to seed source suggests that these are not general population characteristics.

4. Western and northern sources grow more slowly than southern and eastern sources. This conclusion would follow that of many other species. However, there is probably a strong interaction with site as the first conclusion suggests, and it may not be valid in all cases.

5. Sources that show distinctly different characteristics from most include the Connecticut and South Carolina Coastal sources. It is not impossible that introgression with closely allied species (Juniperus horizontalis and Juniperus silicicola) is involved. Western sources which appear very similar may also show introgression with the related Juniperus scopulorum and Juniperus ashei. Such introgression has been reported in the literature (USFS, 1966).

6. The growing of seedlings in one local nursery as transplants for a year or more tends to reduce although it does not eliminate variation in stock grown under a wide diversity of conditions. This method could be used, then, as a means to obtain a wide variety of seed source material for experimental purposes in those cases where the growing of stock from seed is not practicable.

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GEOGRAPHIC VARIATION IN GROWTH AND WOOD QUALITY OF LOBLOLLY PINE IN NORTH CAROLINA

Clark W. Lantz[1/] and Julian G. Hofmann[2/]

ABSTRACT

Two studies of geographic variation in growth and wood quality of young loblolly pines in North Carolina have indicated that the overall performance of coastal seed sources has been superior to that of Piedmont, sandhills and fall line seed sources. Coastal sources produced up to 12 per cent greater heights and up to 30 per cent greater volumes and dry weights than other sources. Variation in wood specific gravity and moisture content was primarily associated with plantation location, with all sources exhibiting their highest specific gravities and lowest moisture contents in coastal plantations. In a comparison of loblolly with slash pine in coastal and fall line plantations, loblolly sources were from 21 to 35 per cent taller, produced from 12 to 47 per cent greater volumes, and had from 7 to 38 per cent more dry weight than slash.

INTRODUCTION

Recent information on geographic variation in the southern pines has indicated the possibility of important amendments to the hypothesis of the superiority of local seed sources. In a summary of the first ten years of the Southwide Pine Seed Source Study, Wells and Wakeley (1966) have stated the general conclusions that seedlings from western sources have demonstrated higher survival and lower fusiform rust (Cronartium fusiforme) infection than seedlings from more easterly sources. However, seedlings from coastal sources have usually grown faster than seedlings from inland sources. In a study of geographic variation of loblolly pine in Georgia, Kraus (1968) confirmed these results with only minor exceptions which were apparently due to local site conditions in the Georgia flatwoods. Coastal sources of loblolly pine planted in a 13-year-old plantation of the Southwide Pine Seed Source Study in Alabama have also exhibited greater volumes and dry weights than inland sources (Saucier and Taras, 1968). The two studies reported here present additional data illustrating geographic variation of loblolly pine in North Carolina for both wood and growth characteristics.

1/ Graduate assistant, N. C. State University Cooperative Tree Improvement and Hardwood Research Programs, School of Forestry, N. C. S. U., Raleigh

2/ Project Forester, Albemarle Paper Company, Roanoke Rapids, N. C.

DESCRIPTION AND PROCEDURES

The two separate studies in this report have been summarized together because of similarities in objectives, designs, and results. The primary objective of both studies was to evaluate the effect of the seed source of loblolly pine on growth and wood quality in North Carolina. The first study (NCSU) was initiated from a series of six seed source areas, established as part of the variation studies summarized by Thorbjornsen (1960). These seed source areas were located on an east-west transect extending from the lower coastal plain to approximately the western limit of the natural range of the species. Each seed source area was composed of three natural stands, located at least one mile apart. Each of these stands was sampled with a collection of open-pollinated seed from five "accessible" trees within the stand. On the basis of topography and soils these seed source areas were grouped into the following provinces: coastal, areas 1(Jacksonville), and 6 (Magnolia); sandhills,3/ areas 7 (Cedar Creek), and 8 (Raeford); Piedmont, areas 9 (Rockingham), and 10 (Wadesboro)(Figure 1).

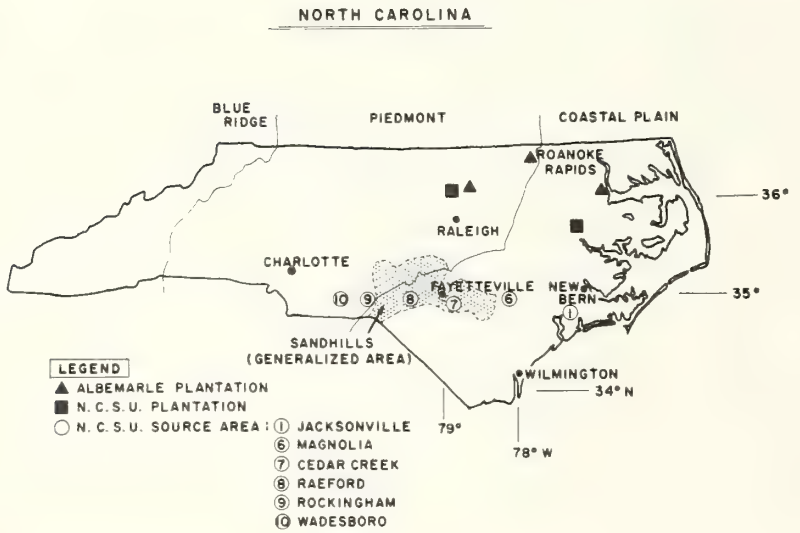

Figure 1. Plantation and source area locations

3/ sandhills: a distinctive area of well-drained and excessively-drained soils located in the coastal plain-Piedmont transition zone in the southern part of the state. The characteristic soil association is Lakeland-Norfolk.

Seedlings from each of the source stands (a total of 18 individual stands) were planted in a randomized, complete-block design, at a 7 x 7-foot spacing, in square, 25-tree plots, replicated four times in each plantation. The coastal plantation located near Washington (Beaufort County) had a site index of 85 and moderately well drained soils, while the Piedmont plantation near Creedmoor (Granville County) had a site index of 80 and well drained soils. Both plantations were in the seventh growing season when the study data were obtained.

The second study (Albemarle) originated from industrial seed collections representing natural stands within coastal, fall line,[4/] and Piedmont provinces of the state. Seedlings from each source were planted with the use of the same plantation design as in the NCSU study, with plantations located in each of the three provinces (Figure 1). A commercial lot of slash pine (seed source unknown) was included in the coastal and fall line plantations. The coastal plantation located near Edenton (Bertie County) had a site index of 90 and was situated on imperfectly drained soils, while both fall line and Piedmont plantations had site indices of 85, with well drained soils. These were located near Roanoke Rapids (Halifax County) and Louisburg (Franklin County), respectively. These plantations were in the fifth growing season when the study data were obtained.

Due to the effects of planting mortality, widespread mouse damage, logging damage, fusiform rust infection, and differential competition, there was a great variation in the number of surviving trees on each plot in the NCSU study. Therefore, the ten largest trees in each plot were selected as the potential crop trees of the plantations. Each of these trees was felled, a wood disk from one to two inches in thickness was obtained at breast height, and the total height and diameter at one-half height was measured and recorded. The total number of trees measured and sampled in this study was 1,109. In the Albemarle study, heights and diameters at breast height were measured for all living trees in each plot (945 trees). Wood disks were obtained from four randomly selected trees per plot (192 trees). In order to make the two studies as comparable as possible, growth data from the Albemarle study were converted to a 10-crop-tree basis. (The bias resulting from this conversion appeared to be uniform for all sources.)

The methods of handling wood disks and subsequent laboratory analysis followed the procedures given by Zobel, et al. (1968). Because of the young age of the trees, only juvenile wood was obtained. Since previous studies had indicated only minor variation in the resin content of wood of young trees (e. g., Stonecypher and Zobel, 1966), only unextracted specific gravities were obtained. All moisture content percentages were calculated on a dry weight basis. Analyses of variance were calculated on the original area and seed source means, using a nested analysis procedure. Total tree wood volumes were

4/ Fall line: a poorly defined transition zone between the coastal plain and the Piedmont, characterized by topography and soils which are common to both provinces.

calculated from the formulas of Perry and Roberts (1964). Conversions to total-tree dry weights were accomplished with the following formula: 62.43 (specific gravity) x (volume in cubic feet) = total tree dry weight in pounds (Zobel, et al., 1965). Province means for the NCSU study are presented in Table 1 and Figure 2. Loblolly source means for the Albemarle study appear in Table 2 and Figure 3, while comparisons between slash and loblolly are included in Table 3 and Figure 5.

RESULTS

Growth

In general, the differences in growth between plantations were relatively small (Figures 2 and 3). The only statistically significant differences in growth between plantations were the height differences in the Albemarle study.

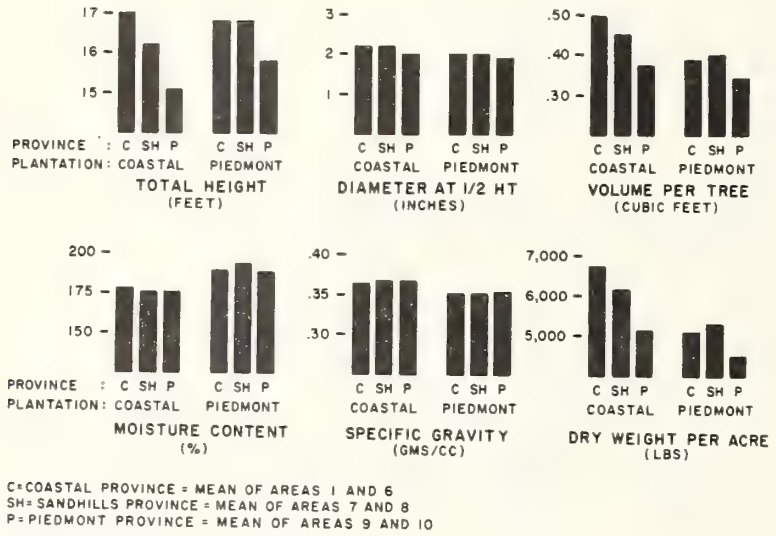

Figure 2. NCSU study: growth and wood quality-province means by plantation

Plantation means for height in this study covered a range of 1.8 feet while in the NCSU study the range of plantation means was only .4 feet. There was little variation in diameter in either study. The mean volume per tree was

greatest in the coastal plantation of the NCSU study, while coastal and Piedmont plantations were about equal in volume in the Albemarle study. In the Albemarle study the fall line plantation mean was considerably lower than the coastal and Piedmont plantation means for all growth characteristics.

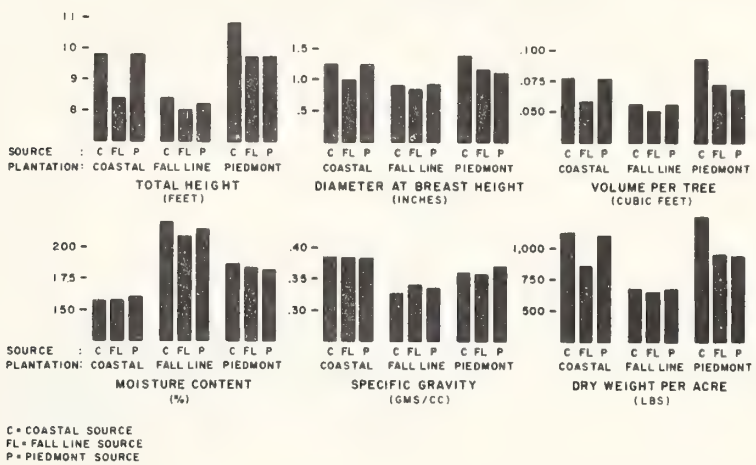
SOURCE : C FL P
PLANTATION: COASTAL FALL LINE PIEDMONT
TOTAL HEIGHT (FEET)
DIAMETER AT BREAST HEIGHT (INCHES)
VOLUME PER TREE (CUBIC FEET)
MOISTURE CONTENT (%)
SPECIFIC GRAVITY (GMS/CC)
DRY WEIGHT PER ACRE (LBS)
C = COASTAL SOURCE
FL = FALL LINE SOURCE
P = PIEDMONT SOURCE

Figure 3. Albemarle study: growth and wood quality-source means by plantation

The variation in height within plantations was statistically significant only for the differences between seed source areas in the NCSU coastal plantation. In this plantation, province means for both height and volume per tree followed a stepwise pattern from the coastal province to the Piedmont province (Figure 2). When the seed source area mean heights were plotted in relation to their geographic origin (Figure 4) the mean height of the two areas in each province appeared to be quite uniform in the coastal plantation, while in the Piedmont plantation there appeared to be a clinal relationship between the location of the seed source area and its height.

The growth differences between provinces and sources in the other plantations did not follow a consistent pattern, as there was considerable shifting of relative position from one plantation to the next. In general, trees from coastal sources produced the greatest heights and volumes. The coastal province and source means (averaged over all plantations) were greater than those of the other provinces and sources in both studies.

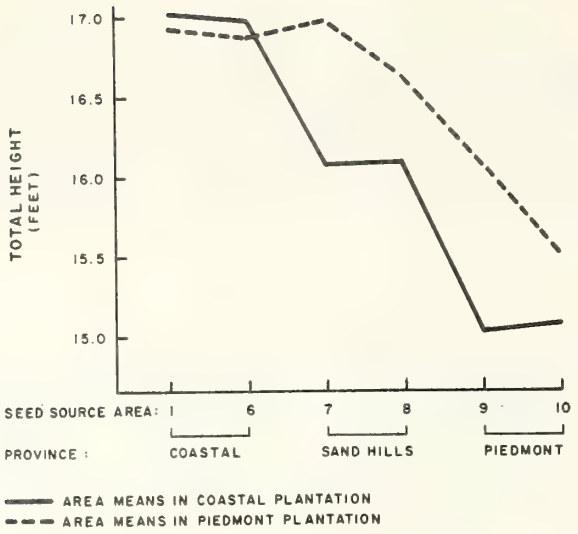

Figure 4. NCSU study: seed source area mean heights related to geographic origin

Wood Quality

There was a great amount of individual tree variation in both specific gravity and moisture content. On a plot-mean basis, however, the differences between sources within the same plantation were relatively slight. Significant differences in specific gravity and moisture content were observed between plantations in both studies. In each study, the highest specific gravity values and the lowest moisture contents were recorded in the coastal plantations. The highest moisture contents recorded in either study were those from the Albemarle fall line plantation, where all source means were greater than 200 per cent.

The frequently reported negative relationship between specific gravity and moisture content (Zobel, et al., 1968) was evident in these studies, with only a few minor exceptions. There appeared to be no meaningful relationships between either specific gravity or moisture content and the growth characteristics which were evaluated.

The economic importance of the volume and specific gravity differences between plantations became more evident when individual tree volumes were converted to dry wood weights per acre. (A hypothetical acre was assumed to contain 600 trees of the same dimensions and wood properties as those of the study trees.) In the NCSU study, a hypothetical coastal acre would have produced 6,016 pounds of dry wood while trees from the same sources planted

in the Piedmont would have produced 4,968 pounds, a difference of more than one-half ton of dry wood per acre in 7-year-old plantations (Table 1). The average yield of the coastal province for both plantations was 169 pounds more than the average yields of the sandhills province, and it was 1,067 pounds more than that of the Piedmont province. In the Albemarle study, coastal and Piedmont plantations would have produced about the same dry weight per acre, which amounted to 365 pounds more than the yield of the fall line plantation. The average yield of the coastal source for all plantations was about 101 pounds more than that of the Piedmont source and about 198 pounds more than that of the fall line source (Table 2).

Loblolly vs. Slash

The inclusion of a commercial lot of slash pine in the coastal and fall line plantations of the Albemarle study provided some interesting data on the comparative performance of the two species grown under the same environmental conditions. In the coastal plantation the mean height of all loblolly sources was 35 per cent greater than the slash mean height; and the coastal and Piedmont loblolly sources each averaged 42 per cent taller than the slash (Table 3, Figure 5).

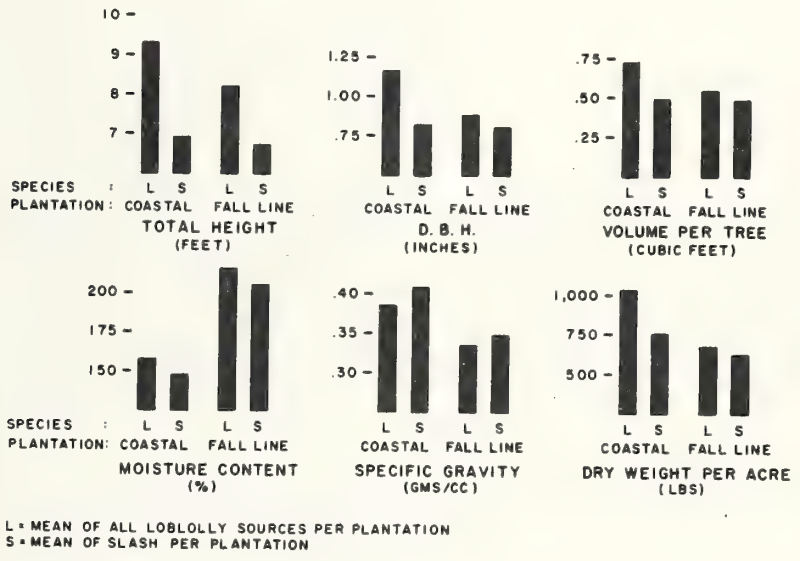

Figure 5. Albemarle study: growth and wood quality of loblolly and slash pine by plantation

The mean volume of all loblolly sources in the coastal plantation was 47 per cent greater than that of the slash, a rather large difference at six years of age. In the fall line plantation, loblolly sources exceeded the slash mean height by 22 per cent while the coastal and Piedmont sources combined were about 25 per cent taller. The mean volume of loblolly was 12 per cent greater than the slash in this plantation. Combining the data from both plantations resulted in a 29 per cent superiority in both height and volume of loblolly over slash. Slash exhibited a higher specific gravity and lower moisture content than any of the loblolly sources in both plantations.

When total tree dry weights for the two species were compared it was evident that the slightly higher specific gravity of the slash was relatively unimportant in comparison with the large volume superiority of the loblolly. For example, the loblolly with 47 per cent greater volume in the coastal plantation had 38 per cent more dry weight than slash, even though the latter had a higher specific gravity. On a per acre basis, the difference in dry weight between the species would be considerable, even at this age. As a hypothetical example, assuming 600 trees per acre of the same dimensions and wood properties as those in the coastal plantation, total yield of dry wood per acre of loblolly would amount to 1,031 pounds compared to 752 pounds from one acre of slash, or a difference of 279 pounds per acre. The often-mentioned early growth superiority of slash certainly does not apply to the conditions of this study. Although these plantations are far from the natural range of slash pine, the soils of the two plantations are typical of many areas in the South where slash has been extensively planted.

DISCUSSION

Growth

The small differences in growth characteristics between plantations in both studies do not seem unusual in view of the young age of the plantations (5 and 7 years) and the narrow range of site index (80 to 90). It does seem of interest that in the Albemarle study all sources, including the fall line source, grew slower in the fall line plantation than in other locations. This may have been the result of an unusual plantation site for which none of the three sources were well adapted.

The overall superiority of the coastal sources in both studies is in good agreement with the previously cited reports by Kraus, Saucier and Taras, and Wells and Wakeley. The fall line source, which might have been expected to demonstrate a wide adaptability to plantation location, recorded the poorest overall performance of any source in the Albemarle study. It is possible that heavy cutting in fall line areas has resulted in a depletion of the genetic quality of these stands. Since the soils in fall line areas are frequently better drained than those in adjacent areas, many fall line tracts are heavily

logged during wet weather. Under these circumstances, continued overcutting over a period of many years could be expected to reduce the genetic quality of the stands in this area.

Although detailed comparisons between individual seed source stands in the NCSU study were not made, seedlings from one of the coastal stands were outstanding in all characteristics. This source (one stand in the Jacksonville area) had the greatest mean height for both plantations combined and a relatively high specific gravity in both plantations. It is interesting to note that seedlings from this same county (Onslow) performed very well in several plantations of the Southwide seed source study (Wells and Wakeley, 1966). The Onslow County source ranked first in both height and volume in plantations in Alabama and Louisiana, first in volume and second in height in a Mississippi plantation, and first in height and third in volume in an Arkansas plantation.

The evaluation of wood quality often raises a question of the relative importance of the environment compared with the genetic characteristics of the stand. These studies present evidence that the environmental control of juvenile wood specific gravity is stronger than the genetic control. In both studies, differences in specific gravity between plantations were much greater than the differences between seed sources within plantations. The large within-plot variation should not be overlooked, however, as this provides the raw material for gains via individual tree selection. Furthermore, these studies should not be interpreted as evidence that meaningful differences in specific gravity do not exist between geographic areas within the state. The stands, areas, and commercial collections from which these studies originated were not intended to be representative samples of the natural populations of loblolly pine within the state.

The evidence relevant to the degree of genetic divergence of loblolly pine within the state appears to be inconclusive. Significant differences between sources within plantations were found in only one plantation (NCSU coastal). In this plantation each province appeared as a well-defined "step" in the relationship between seed source location and total height (Figure 4), indicating greater differences in height growth between provinces than within. On the other hand, the same relationship in the Piedmont plantation appeared to be clinal, with height growth primarily related to an environmental gradient. In the NCSU study, both coastal and Piedmont sources were taller in their "native" plantations than in other locations, indicating the possibility of adaptive differences in height growth. These growth patterns appear to indicate that there are geographically related genetic differences in growth within the species. It is not clear, however, whether these differences reflect racial, ecotypic, or clinal divergence within the species.

Although coastal sources have performed well in several locations in these studies, extreme caution should be exercised regarding the planting of coastal sources outside of their natural range. Even though coastal sources have

produced greater volumes of wood than Piedmont, fall line, or sandhills sources, these evaluations were made at only one-sixth to one-third of an "average pulpwood rotation." The risk of climatic and/or biotic disaster is always present with sources which are not endemic to their environment. The damage from a late frost, ice storm, prolonged drought, or severe insect or disease attack can easily erase the potential economic gain from higher growth rates. The previously mentioned evidence of genetic divergence within the species suggests that adaptive differences do exist between geographic areas of the state. Certainly some of these differences are in the form of "built-in insurance" for natural hazards to which the trees have been exposed and on which natural selection has acted. Until more definitive results are available from studies of older trees it does not seem advisable to plant non-native seedlings on a commercial basis.

CONCLUSIONS

1. Within the state of North Carolina, coastal seed sources of loblolly pine have demonstrated the ability to grow more rapidly than sandhills, fall line, or Piedmont sources on a wide range of plantation locations. This faster growth was not associated with any reduction in wood quality.

2. The specific gravity and moisture content of juvenile wood of all sources was affected more by plantation location than by genetic differences between the seed sources.

3. The overall performance of all sources studied is indicative of local genetic differentiation within loblolly pine in North Carolina. There was little evidence of true geographic races.

4. Loblolly was far superior to slash pine in coastal and fall line plantations, producing up to 47 per cent greater volumes and 38 per cent more dry weight.

Table 1. NCSU Study: Growth and wood quality of coastal, sandhills, and Piedmont seed sources by plantation location

	Plantation Location	Province			Plantation Means
		Coastal	Sandhills	Piedmont	
Total Ht. (Ft.)	Coastal	17.0	16.2	15.1	16.1
	Piedmont	16.8	16.8	15.8	16.5
	Province Mean	16.9	16.5	15.5	
Dia. @ 1/2 Ht. (In.)	Coastal	2.2	2.2	2.0	2.1
	Piedmont	2.0	2.0	1.9	1.9
	Province Mean	2.1	2.1	2.0	
Vol. (Cu. Ft.)	Coastal	.494	.452	.376	.440
	Piedmont	.390	.403	.342	.378
	Province Mean	.442	.427	.359	
Wood Moist. Cont. (%)	Coastal	178	175	175	178
	Piedmont	189	193	188	190
	Province Mean	184	184	182	
Wood Sp. Gr.	Coastal	.362	.366	.367	.365
	Piedmont	.350	.350	.352	.350
	Province Mean	.356	.358	.360	
Wood Sp. Gr. (Lbs./Cu. Ft.)	Coastal	22.6	22.8	22.9	22.8
	Piedmont	21.9	21.9	22.0	21.9
	Province Mean	22.2	22.3	22.5	
Dry Wt./Tree (Lbs.)	Coastal	11.2	10.3	8.6	10.0
	Piedmont	8.5	8.8	7.5	8.3
	Province Mean	9.8	9.6	8.1	
Dry Wt./Acre (Lbs.)	Coastal	6,696	6,187	5,165	6,016
	Piedmont	5,112	5,284	4,510	4,968
	Province Mean	5,904	5,735	4,837	

Note: Each province mean represents the mean value of the two seed source areas within the province.

Table 2. Albemarle Study: Growth and wood quality of coastal, fall line and Piedmont seed sources by plantation location

	Plantation Location	Source			Plantation Means
		Coastal	Fall Line	Piedmont	
Total Ht. (Ft.)	Coastal	9.8	8.4	9.8	9.3
	Fall Line	8.4	8.0	8.3	8.2
	Piedmont	10.8	9.7	9.7	10.0
	Source Mean	9.6	8.7	9.2	
Dia. @ B. H. (in.)	Coastal	1.25	1.00	1.24	1.16
	Fall Line	.90	.81	.92	.88
	Piedmont	1.38	1.15	1.10	1.21
	Source Mean	1.18	.99	1.09	
Vol. (Cu. Ft.)	Coastal	.078	.059	.077	.072
	Fall Line	.055	.051	.056	.054
	Piedmont	.093	.072	.068	.078
	Source Mean	.075	.061	.067	
Wood Moist. Cont. (%)	Coastal	158	157	160	158
	Fall Line	221	209	215	215
	Piedmont	187	184	182	184
	Source Mean	189	183	186	
Wood Sp. Gr.	Coastal	.388	.385	.383	.385
	Fall Line	.328	.340	.335	.334
	Piedmont	.360	.358	.370	.363
	Source Mean	.358	.361	.363	
Wood Sp. Gr. (Lbs./Cu. Ft.)	Coastal	24.19	24.04	23.88	24.04
	Fall Line	20.45	21.23	20.91	20.86
	Piedmont	22.48	22.32	23.10	22.63
	Source Mean	22.37	22.53	22.63	
Dry Wt./Tree (Lbs.)	Coastal	1.88	1.42	1.85	1.72
	Fall Line	1.13	1.08	1.17	1.13
	Piedmont	2.08	1.60	1.57	1.75
	Source Mean	1.70	1.37	1.53	
Dry Wt./Acre (Lbs.)	Coastal	1,131	853	1,109	1,031
	Fall Line	677	650	670	676
	Piedmont	1,250	959	944	1,051
	Source Mean	1,019	821	918	

Table 3. Albemarle Study: Growth and wood quality of loblolly and slash pine in two plantations

	Plantation Location	Species		Plantation Mean
		Loblolly	Slash	
Total Ht. (Ft.)	Coastal	9.3	6.9	8.0
	Fall Line	8.2	6.7	7.5
	Species Mean	8.8	6.8	
Dia. @ B. H. (In.)	Coastal	1.16	.82	.99
	Fall Line	.88	.80	.84
	Species Mean	1.02	.81	
Vol. (Cu. Ft.)	Coastal	.072	.049	.061
	Fall Line	.054	.048	.051
	Species Mean	.063	.049	
Wood Moist. Cont. (%)	Coastal	158	148	153
	Fall Line	215	205	210
	Species Mean	187	176	
Wood Sp. Gr.	Coastal	.385	.408	.397
	Fall Line	.334	.348	.341
	Species Mean	.360	.378	
Wood Sp. Gr. (Lbs./Cu. Ft.)	Coastal	24.04	25.44	24.74
	Fall Line	20.86	21.69	21.28
	Species Mean	22.45	23.57	
Dry Wt./Tree (Lbs.)	Coastal	1.72	1.25	1.49
	Fall Line	1.13	1.05	1.09
	Species Mean	1.43	1.13	
Dry Wt./Acre (Lbs.)	Coastal	1,031	752	892
	Fall Line	676	630	653
	Species Mean	854	691	

Note: Loblolly means = means of all loblolly sources in the respective plantation.

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SESSION IV

Seed and Seedling Orchard Management

Moderator: Aaron Jordan

From left to right: John E. Morris, A.R. Gilmore, William J. Lowe, R.C. Schmidtling, Aaron Jordan, Frank Vande Linde, Ray Marler, R.J. Varnell, Charles D. Webb

SEED ORCHARD PROBLEMS - IN RETROSPECT AND ANTICIPATION

R. L. Marler 1/

Problems confronting seed orchard managers are discussed including those everyday problems of establishment, maintenance, record keeping and protection.

In addition, certain public relation problems are mentioned which bear on harmony and good will from both "outsiders" and "insiders".

Finally, questions are raised concerning anticipated biological problems and man's possible control over.

EVERYDAY PROBLEMS

Establishment

Establishment includes readying the land for the orchard and then establishing the grafts by whatever method one might be using.

For many of us readying the land for the orchard includes land clearing and so that attendant problems of avoiding soil compaction, Fomes annosus (if the previous stand contained much pine), providing proper drainage and leveling should be considered. Because we're talking money top management may balk at what to them may seem excessive costs but in the long run we can save money by doing a careful and thorough land clearing job before the first grafted tree is placed on it. You will note that I mentioned leveling — since we envision collecting our seed by vacuum sweeping seed in our loblolly pine seed orchards we will need level terrain in order to recover as much of the seed as possible. Therefore, it's entirely possible that many of us who established our orchards before the advent of the pine seed vacuum will have to go back into our orchards and level the best way we can by filling or otherwise leveling the seed orchard surface as best we can.

Oftentimes it is necessary to clear an isolation strip around the perimeter of our orchards. The purpose of this strip is to reduce contamination from unwanted pollen outside the seed orchard. I've been convinced for some time that where we are establishing loblolly pine seed orchards almost anywhere within its natural range that we will have unwanted outside pollen in our orchard. Under proper conditions we know that pine pollen will "fly" for long distances. The magic number is at least 400 feet and this is what most of us are using in making allowances for our isolation zone. However, we've noticed for some time that we are getting filled seed in the orchard on ramets much further than 400 feet from a known pollen source. The implication of Squillace's (1967) study with slash pine showed that when male flowers are absent (or extremely rare) in the orchard, wind-borne pollen from stands more than 400 feet away is sufficient to pollinate the female flowers effectively. This possibility of outside pollen contamination will probably prove more of a problem to us earlier in the history of our orchards than later due to the availability of pollen from within our orchards. As our orchards mature, more and more pollen should become available thereby hopefully "saturating" the orchard with seed orchard pollen. In the early stages, however, much of this "saturation" may well come from the outside and we may as well recognize it.

1/ R. L. Marler, Chief, Applied Forest Research, Virginia Division of Forestry, Stationed at Charlottesville, Virginia.

Since many of us are still grafting, I would be remiss in not mentioning it as a problem. For us it's a problem because it comes at a time of the year when we would like to be doing more control pollinating and other important seed orchard work. To others, just getting started with their seed orchards, a certain amount of apprehension is only natural. In any event, grafting is time consuming and a technique or techniques suitable to your particular needs must be worked out. It is always somewhat amusing to see, yet frustrating at the same time, the inordinate interest displayed by "outsiders" and "insiders" in grafting. However, once a grafting technique is worked out for your particular needs it's just another mechanical process and is merely a means toward the end.

Before leaving grafting, graft incompatability should be mentioned. Graft incompatability costs us both in time and the loss of valuable clones. Clark Lantz (personal communication) informed me that data obtained as a result of a questionnaire in which 19 organizations participated that 22% of the loblolly pine clones grafted showed definite signs of incompatability. Lantz went on to say that he estimates the overall clonal loss is approximately 15%. R. Corti and associates (1968) found in essence that grafting incompatability is a complicated phenomenon. Since a solution does not appear to be in sight for the present most of us are "by-passing" the problem by substituting other clones but this has cost us both money and time, and has somewhat complicated our progeny testing program.

Graft incompatability, other mysterious physiological problems, plus just plain transplanting mortality often makes it necessary to replant or replace grafts in the orchard. Due to the competitive effects of adjacent grafts a point in time is soon reached when replacement planting is inadvisable. In my opinion this can come as soon as three years following the establishment of the main orchard. It isn't the question whether or not a graft transplanted at a later date will live, but a more relevant question is what such a transplant would contribute to the seed orchard. Large holes excepted I've seen transplanting done where the grafts are sometimes "buried alive".

Records

Good records are most vital and necessary to successful seed orchard management. Seed orchard management is a job of details and we need to have some way of recording these various jobs. Quite obviously, in order to be helpful, records must provide us with information needed as well as record history.

A sample of the type records to be kept are: a. cost, b. establishment, c. various maintenance operations (such as fertilization, insect and disease control, mowing, etc.), d. maps showing location of clones, etc., e. flowering data by clones, and f. roguing just to mention a few.

We have tried various record keeping methods including Keysort and, to date, have not found the ideal system. In our operation where we have nearly 28,000 ramets to manage and several seed orchard locations involved good records are a must but most difficult to maintain.

Record keeping - a mundane job perhaps but nonetheless necessary and a big one. Ask any seed orchard manager.

PUBLIC RELATIONS

People Problems

I've chosen to categorize so called "people" problems which could be categorized as public relation problems as falling into two categories: those within the various tree improvement programs which would include genetic workers, and "without". Only forester-type personnel will be considered.

One of our "without" problems concerns itself with the fact that we may have oversold the value of our programs (I'll discuss this later also as a "within" problem) to the point where many silviculturists simply don't believe our claims and view the programs with distruct. I believe we should keep in mind that genetics is just one of the methods whereby one can exercise control over wood quality. Many silvicultural operations such as initial spacing, thinning, fertilization, length of rotation exert a strong effect as well as the genetic material used. These are facts which the silviculturists recognize and those of us in tree improvement programs should also. We must remember that it will be the silviculturists and forest managers, in the long run, who will be working with the seed orchard progeny produced. I would suggest we maintain firm ties with them and not make exaggerated claims as to the genetic gains expected. I'll go into detail later concerning the nature of these claims.

Another "without" problem and related to the above is the fact that tree improvement - genetics is the current glamour field in forestry. Witness the industry ads in magazines and the many newspaper feature articles on the subject. It is only natural that those outside the program will feel some resentment and envy. I can't offer a solution. I can only point it out as a problem since such resentment can affect our programs.

One of our "within" problems that we have is overexaggerating genetic gains expected. All of us are pleased and proud that early results of progeny tests look extremely good. However, because these test results are still early I believe it would be most unwise and premature to extrapolate these early results too far into the future. Zobel (1967) says that even though "we may get 15 percent volume improvement through selection of superior trees, maybe 15 percent by fertilization, maybe a 4 percent in wood specific gravity, and a 10 percent gain through insect and disease resistance - but those percentages just can't be added to determine total gain. It doesn't work that way because each of these characteristics are correlated to each other."

As Van Buijtenen (1969) also points out ".... quantity and quality properties cannot be manipulated independently, but are strongly interrelated. A change in one of the properties invariably will modify others. In the southern pines, for example, specific gravity and growth rate have been shown to be strongly and negatively correlated." For example, suppose one fertilizes and thereby increases growth. There is a good chance that this increase in growth will be accompanied by a decrease in specific gravity. Fertilization could also conceivably adversely affect the insect and disease resistance which we have bred into our seed orchard progeny. Furthermore, with each step of improvement the gain curve may flatten off and we soon reach an economic limit whereby it may cost us too much for the gain achieved. Perhaps our biological improvement

possible may total 50 percent, but we may find it expedient to stop at some figure less than 50 percent. The thought occurs that we may have to "de-sell", if necessary, to make sure we remain practical and realistic on genetic gains expected. Quite frankly, we have justified and sold our programs on much smaller gains and perhaps we need a return to some of these more modest figures quoted.

Honest differences of opinion still exist among forest geneticists as to the best method to use in order to achieve our ends — which should be the production of improved seedlings. You will perhaps recall the open discussion of the various methods one should use which were published in the Journal of Forestry a few years ago. In my opinion this sort of disagreement could better be worked out between and among those geneticists concerned. It had no place being aired in a publication which most foresters read because it only created problems and raised questions. It only tends to confuse. I can speak from experience. Furthermore, I don't believe the opposing geneticists really convinced one another anyway so why bother in the first place.

ANTICIPATED PROBLEMS

After reading this section the reader may rightly question the section heading since some of the problems which follow are present day ones. However, it is felt that, for the main, the major impact of the problems which follow lie in the future.

Soil Compaction

Soil compaction and its attendant problems is going to be troublesome. Aside from compaction oftentimes caused in our initial land preparation throughout a given year numerous vehicular trips are made in our orchards. Each one contributes towards the soil compaction problem which will with time be compounded. The heavier the soil the more severe our problem will become. Also, wet weather vehicular trips are especially damaging. Floatation type equipment will help but will not completely alleviate the problem.

I do not believe sub-soiling is going to be the universal solution to soil compaction. Not only will we possibly be subjecting the orchards to possible disease such as (Fomes annosus) but also physical root damage is bound to occur. Sub-soiling also tends to make the soil surface rough which will create problems when we use our seed harvester vacuum which will require a smooth surface for maximum efficiency.

Disease

Fomes annosus is just a single example of the diseases we must consider. Orchards further south than Virginia I'm sure would also list Cronartium as one of their problems. With respect to Fomes annosus our fertilizing will most certainly bring the root systems up nearer the surface thereby increasing chances of root damage through mowing, for example, and certainly increases the risk of infection.

There is quite a bit of physical damage to trees in a seed orchard as a

result of using various types of equipment, i.e. mowers, etc., which also will provide avenues of infection. We know what usually causes this damage but it's most difficult to prevent.

Anything intensively managed such as a seed orchard is bound to have numerous diseases reported and they have been. I am sure we will learn of new ones as well. In our orchards these perhaps do not fall into the disease category as such but we also have unexplained physiological problems some of which eventually will kill the tree. I sometimes feel we may be minimizing losses caused by unexplained physiological factors and that if these losses were totaled we might be unpleasantly surprised.

Insects

As I now see it we are going to have to draw battle lines with respect to insects, especially cone and seed insects. We can perhaps tolerate aphids, red spider mite, etc., but ultimately flower, cone and seed insects must be reckoned with.

DeBarrs (1969) study in slash pine points up the need for such control. DeBarrs found that "of 442 flowers examined while still in the twig-bug stage of development in January that 52 percent had been damaged by thrips. Observations made in mid-March revealed that 38 percent of the 442 female flowers originally observed never matured to conelets because they had been killed by thrips in early February, prior to pollination. Of the 274 flowers that developed into first-year conelets, 50 percent had been injured by thrips prior to pollination; the damage ranged from slight to severe."

Presently all roads lead to systemics. At first glance using these systemics appears easy. One just merely broadcasts or disks in the systemic, if its in granular form, and wait for it to be assimilated by the tree and go to work. In actual practice it isn't quite that simple, however. In my organization we are using granular Thimet so my remarks will be confined to its use; however, other granular-type systemics have reacted similarly. To begin with, these systemics are extremely toxic and extreme care should be exercised in using them. We used nearly 5,000 pounds of Thimet this past season alone and this entails considerable exposure of a sort to personnel involved. The composition of these organophosphate compounds such as is contained in Thimet is apparently similar to nerve gas. Toxicity builds up and there is a threshold level in humans which should be closely watched. At the present we require our seed orchard personnel coming in contact with Thimet to take three blood tests annually so that the cholinesterase level may be watched. We also keep an antidote, atropine sulfate, on hand. To those of you using toxic materials, such as these systemics, I would recommend you locate the Poison Control Center nearest you if you do not already know it. We are observing every safety percaution we can think of and it still causes us considerable concern.

Where should these granular systemics be placed for maximum effectiveness? What is the effect of cover, tree size, and soil? We've noticed differences with respect to insect control for each of these.

What are the "carry-over" effects, if any? Do we apply once a year, if so, when? Do we need "booster shots" later on in the season; if so again — when?

What is the effect, both short term and long term, on flowering when one uses these systemics?

What are the modes of absorption, translocation, and the metabolism effects within the tree?

These are just some of the questions I have concerning the use of these systemics.

To date, I am disappointed with the effects of the entomologists, with respect to providing good recommendations for insect cone and seed protection. I believe they've been too defensive. Not too long ago the entomologists kept asking for a "realistic and reliable estimate of the increased monetary value of a pound of improved seed so that we can have a cost benefit ratio study to determine whether or not the expenditure of insect control funds are justified on the basis of increased seed yields." I noted in a recent copy of Minutes - Contact Men's Meeting (1968) published by North Carolina State University that Merkel calculated that for slash pine that from $2.50 to $3.50 per tree could be spent for chemical control of insects and that seed yield was found to be approximately 2.5 times greater from treated areas than untreated areas. Perhaps with this incentive we can look for increased activity and better recommendations from entomologists in prescribing for effective control of cone and seed insects.

Flowering

Flowering is apparently quite clonal and presently we have perhaps 20 percent of our clones which are producing flowers in appreciable quantity. Bergman (1968) reports on the cone production varying greatly among clones with highly significant differences. What if progeny tests reveal these highly producing clones to be poor with respect to both general and specific combining ability and that roguing is in order? Should this prove the case and we lose the production from some of our most prolific clones, our cone and seed production could drop sharply. Yet, unless a clone can produce flowers, at least in moderate numbers, it doesn't do us much good in the orchard.

Do we declare a moratorium with respect to the time one can wait to see whether or not a clone will produce in quantity? If so, how long? Most of us are "waiting out" our low producers and hoping for the best. What is the age-size relationship to flowering? What assurance, if any, do we have that a clone will be a late "bloomer" with respect to flowering? I am concerned because some clones are just occupying space within our seed orchards with little evidence that these will produce cones in any quantity. Unless a clone can produce cones and seeds, the best phenotype or genotype does not belong in an operational type seed orchard such as most of us presently have.

Bergman also reports that three principal methods have been used to induce heavy flowering; artificial (usually mechanical) disturbance of the tree's transplant and root system, fertilization, and use of "flowering hormones."

The first method has not proven successful and in numerous cases the tree was killed by the treatment.

The method employing "flowering hormones" is still in its infancy and Sato's (1963) work in Japan on response using gibberellins is encouraging. However, most are in agreement that it is unlikely that a simple treatment generally effective in flower production will soon be developed. Furthermore, in order to be practical these hormones would have to be capable of being applied on a mass scale which is no small feat in itself.

In making future selections for our orchards we are going to examine fruitfulness more closely and eliminate those selections which we might have reason to suspect as being low or non-fruitful. Our immediate goal is seed; we'll leave it to others to preserve these non-fruitful genotypes if they wish to.

This brings us to fertilization which most of us are using today. The questions then become what, when, and how much? We will apparently have to learn these answers through trial and error. For example, we have a fertilizer study in progress in cooperation with Dr. C. B. Davey and Mr. Steve Webster, both of North Carolina State University, which involves nine different treatments and includes two different times of application. Through the results of this study we are hopeful that we can make more effective use of our fertilizer dollar. However, we should recognize that the empirical data obtained from one orchard may not be applicable in other orchards of different soil types. Should the right combinations be discovered Bergman suggests that fertilization increases the differences between clones with different flowering intensities and that good flowering clones often react more positively than poor clones which has the net result in decreasing the number of effective clones in the orchard. Again, what if progeny tests reveal that these high producing clones should be rogued? Matthews (1964) states, that ".... seed orchards exist to produce the greatest possible yield of well-filled viable seed." Quite obviously if it proved necessary to rogue our high seed producing clones we could, in essence, be defeating our purpose.

Flower production by sex may also be affected differently as a result of fertilization. We may find a fertilization treatment which will increase female flower production but decrease male flower production. Webster (private communication) cites recent study data whereby fertilization increased female flower production but reduced males.

To further complicate the fertilization problem Posey (1964) found a great variation between clones and families in the capacity to respond to fertilization. This would perhaps entail an overall assessment of gains realized based on the clones genetic worth and the increased seed yield realized.

Flowering phase - unless our clones or clone flower in phase with at least one other desirable clone we have this problem as well. I believe we only have one alternative in production orchards where we have a clone completely out of phase with other clones and that is to rogue them. To date, we've lost two in one orchard alone and both have been removed.

Loblolly pine is variable with respect to flowering time; this is being bourne out by our flower phenology studies. In Virginia, I am told that we have considerable inter-specific hybridization which takes place between loblolly and pond and/or pitch and we also have noted loblolly and shortleaf hybridizing. Dr. L. C. Saylor (private communication) says we have "tension zones" in Virginia where considerable hybridization occurs. I know that some of our selections have been made within these zones. If so, and our selection is an inter-specific hybrid a further opportunity exists for clones to be out of flowering phase.

CONCLUSION

I do not want to end this talk on a pessimistic note because I really do not feel that way. I have raised just a few of the problems and I know that many of you could add considerably to the list.

In spite of problems raised several years ago when most of us began our tree improvement programs real progress has been made and much has been accomplished. The Southeastern United States is clearly leading the way and we all should take pride in being a part of it. I know I do.

We can anticipate our share of problems yet to come but perhaps these should be expected because our programs are dynamic and fast moving. If we can apply the "know how" that we have and coordinate our efforts I firmly believe we can solve most of these problems. With what is at stake we can do no less.

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SOME PRACTICAL ASPECTS OF SEED ORCHARD MANAGEMENT IN THE SOUTH

Frank Vande Linde
Brunswick Pulp & Paper Company

The nation's population is increasing at a rapid rate, while at the same time productive land acreage is decreasing. Competition for land usage will bring many future problems, and we will be compelled to grow more timber volume on fewer acres.

The forest tree improvement program was initiated with this fact in view and is making steady progress toward a superior forest.

To produce this superior forest we must have a reliable seed source; thus the seed orchard became a must to practically every land-holding company in the South.

It is through continued cooperative efforts such as this today that we have made real progress in the field of tree improvement.

Site

The most important factor pertinent to successful seed orchard management other than tree selection is site. A seed orchard is both an expensive and a long term investment. It requires the best site available. A good site will minimize all management problems.

When selecting a site, one should very carefully evaluate the soil properties for nutrient-supplying and water-holding capacity. The soil profile should be examined and mapped to a depth of four feet. Soil samples should be analyzed for available nutrients, fertilizer recommendations, and soil pests.

The site should be well drained, and if not accessible, made so by proper road construction. If drainage is necessary, construct roads when possible that will serve both for drainage and accessibility.

Isolation should be considered and planned well in advance of seed orchard establishment.

When selecting an orchard site, look at abandoned farm land, upland areas bordering hardwood swamps, and pine and pine-hardwood

islands within hardwood stands. Hardwood swamps and drains serve well as isolation strips for pine orchards.

I feel that minimum requirements for an orchard site would be a site index for slash pine of 85 feet and loblolly of 90 feet. A sandy loam or loamy sand with a depth of 18 to 36 inches over a sandy clay is ideal. Stay away from heavy, poorly drained soils.

Orchard Size and Design

Future seed needs should determine orchard size. Seriously consider future needs, then think in terms of over-supplying rather than bare minimum needs.

Today orchards vary considerably in size -- from five to 600 acres in area. The average orchard size is around 65 acres.

Personally, I would rather have two 50-acre orchards with two different locations than to have one 100-acre orchard. Catastrophies often happen such as hurricanes, fires, ice storms, etc. that could seriously damage a single orchard. It is not wise to place all your eggs in one basket.

Outplanting design varies somewhat from one organization to another. Accepted designs are square, rectangular, diagonal, and combinations of the three. The most common is the square design with random location of clones.

Design is a personal touch to the orchard, and any of the above mentioned will be satisfactory providing clone placement and spacing are carefully considered.

Clones should be so placed that two alike clones will be two removed from each other.

Slash, loblolly, and longleaf orchards should be planted to allow a minimum spacing of 30 feet by 30 feet following roguing. Forty feet by forty feet is not at all unreasonable.

Grafting

Grafting is the best method to propagate pines in the seed orchard. The cleft and side grafts are more widely used.

Other grafting techniques used to supplement seasonal grafting are bottle grafting and inarching.

Air-layering is being used with varying degrees of success.

There are as many ideas about successful grafting as there are grafters present, so my advice to you is, if you have a grafting technique that is giving you satisfactory results - stick with it. Grafting is a skill that improves with practice. Hold on to the skilled grafter.

Grafting can take place in the field, pots, or nursery bed. Each location has its advantages and disadvantages, but do not discount any of the three. They all have a place in the establishment of a seed orchard.

Field Grafting

Two or three seedlings are placed at the spacing desired in the seed orchard. The seedlings are allowed to grow through the summer and field grafted the following spring. Field grafting usually gives good survival and no transplanting problem. However, the grafter is at the mercy of the weather and much time is lost moving from one graft to another.

Field grafting is the best method to propagate longleaf pine orchards.

Pot Grafting

Pot grafting has received much unfavorable criticism stemming from earlier trials. All of you are familiar with pot binding and orchard loss due to root girdling. Rootstocks were allowed to stay in pots too long before grafting. In some cases rootstocks were allowed to stay in pots two seasons before grafting.

Pot grafting can be very successful and helpful in setting up orchards if properly handled.

Grow seedlings in the nursery bed at a wide spacing (8 to 12 inches) and transplant to pots in late November or December. Grafting can take place in January, February, or March. The graft is transplanted to the field when well pin-feathered, usually in April, May, or June. Do not hold rootstocks in pots from one season to another. Pot grafting concentrates grafting efforts and gives the grafter advantage over the weather.

It does, however, remove valuable nursery soil and cause a transplant problem.

Nursery Bed Grafting

Seedlings are grown in the nursery bed at a wide spacing (8 to 12 inches) and grafted while still in the nursery bed. The grafts can be lifted and transplanted to the orchard during early summer or transplanted in the fall.

Nursery bed grafting is somewhat of a compromise between field grafting and pot grafting. It concentrates the grafting problem and calls for less supervision of grafts. As in pot grafting valuable nursery soil is removed in the process of lifting, and the transplant problem is more difficult.

If you are establishing a new orchard and a large number of grafts are necessary, seriously consider the merits of all three grafting locations. Think in terms of taking advantage of the weather and best use of personnel who will be doing the grafting.

CULTURAL PRACTICES

Irrigation

Irrigation of seed orchards is not recommended after establishment. Some watering of small grafts will be necessary when establishing the orchard.

Weed Control

Some degree of weed control must be maintained around small grafts after they have been transplanted to the orchard. This is particularly important during the first two to three years. Weeding around grafts is no small chore. We have scalped around young grafts with a hoe, but it is my understanding that reliable chemicals for weed control are now available. A word of advice -- Use Chemicals With Caution.

The ground cover can best be maintained by mowing. We mow twice a year, during the latter half of May and again in late August or early September before cone harvest.

Disking is not recommended. Continued disking is harmful to tree roots and creates an erosion problem.

Work toward a turf, preferably one of the native grasses of your area, then maintain by mowing.

Fertilization

Wise use of fertilizers is recommended in the seed orchard. I do not believe in throwing fertilizer around because it is relatively cheap. We should have some basis for fertilizing our orchards. There are too many unknowns connected with fertilization to take unnecessary chances. One should strive to keep a balance of soil nutrients in his orchard. This will require periodic soil tests and fertilizer recommendations from qualified personnel.

Until more information is available, I plan to stay away from high rates of nitrogen and stick with complete fertilizers such as 10-10-10, 13-13-13, and 18-18-18.

Pruning

After plants are grafted, some degree of pruning will be necessary on the stock plant. During the early weeks after the graft has taken, make sure the graft stays in a dominant position, clipping off any side limbs that will compete with graft. After graft is well established, remove all limbs from the rootstock.

Pruning will continue to be a necessary tool as the orchard progresses. We go through our orchard during each winter season checking each tree and prune off lower limbs that are drooping, dead limbs, cankered limbs, ramiform branches, and doctor trees with forks and trees that have been the subject of storms. We occasionally find it necessary to top prune a tree, but do not encourage this practice. If necessary to remove a tree from the orchard, we remove the whole tree, root included, with a bulldozer.

All wounds are sprayed or painted with a tree wound compound.

Spraying

Periodic inspection of orchards should be maintained throughout the year to insure early detection of insects and disease. Orchard specialists should familiarize themselves with symptoms and be in a position to consult with a specialist if he does not have a ready cure.

It should be emphasized that use of chemical pesticides can be overdone. Regular scheduled spraying only as a precaution is not recommended. Misuse of insecticides can create problems by destroying natural predators. Spray when necessary, but know what you are spraying for and with, and take all necessary precautions.

Young grafts will need protection from red spider, aphids, and tip-moth. We spray with Malathion for red spider and aphids and apply Thimet to control tip-moth.

Record Keeping

At the beginning of this paper I intimated that tree selection is the most important phase of orchard management with site selection running a close second. This is true, because without the tree and a good site to grow it, there would be no orchard. Progress is also important. Progress is measured by the records you keep.

SOIL MOISTURE STRESS AND TRACHEID LENGTH IN LOBLOLLY PINE

A. R. Gilmore[1/]

Little has been reported on the effect of environmental factors upon tracheid lengths in pines. Wellwood (1960) found no effect of site upon tracheid lengths in western hemlock, and Goggans (1961) concluded, after reviewing the literature, that environmental factors account for very little of the between tree variations that is found in tracheid lengths. On the other hand, Goggans (1962) concluded that summerwood tracheid length is correlated with heredity.

This paper reports the results of an experiment conducted in southern Illinois to determine the effect of soil moisture stress on the tracheid lengths of 18-year-old plantation-grown loblolly pine (Pinus taeda L.). At the beginning of the experiment, the dominant trees in the stand averaged from 6 to 7 inches d.b.h. and were about 40 feet in height. There were about 820 stems per acre with a basal area of 160 square feet. All trees were naturally pruned up to 27 feet in height. The soil under the stand is a silt loam with an impervious fragipan horizon 24 inches below the surface. Competition among individual trees for root space is severe, resulting in rapid soil water depletion during the summer months.

Six treatments were replicated three times on 1/20-acre plots in a randomized block design as follows:

1. Soil moisture was maintained near field capacity (F.C.) in the spring and near the wilting point (W.P.) during the summer.

2. Soil moisture was maintained near the wilting point in the spring and near field capacity during the summer.

3. Soil moisture was maintained near field capacity at all times.

4. When 30 percent of the available moisture in the top 24 inches had been used, the soil was watered to field capacity.

5. When 60 percent of the available moisture in the top 24 inches had been used, the soil was watered to field capacity.

6. Control; normal rainfall.

Trenching was used to prevent lateral movement of moisture and the growth of roots from one plot to another, and plastic covers were used over the soil surface on plots maintained under drought conditions. Soil moisture of the top 24 inches was monitored with a d/M nuclear gauge.

The dominant trees were sampled on each plot. Twelve-millimeter increment cores were taken from the north and south sides of each tree at 4.5 feet above ground so that wood from the last three years growth was included. Two

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1/ Associate Professor of Forestry, Department of Forestry, University of Illinois, Urbana.

wood samples were taken from each increment core, and the tracheids were macerated in a hot hydrogen peroxide-acetic acid solution. Tracheids were mounted on glass slides as described by Echols (1961) and measured using an ampliscope (Echols, 1959) that amplified the tracheids 62.5 times. Duplicate slides of mounted tracheids were made of each wood sample, and all tracheids were measured on each slide (about 25 tracheids per slide). This procedure resulted in approximately 600 measurements for each treatment.

The range and averages of tracheids in each treatment is shown in Table 1. The longest tracheids were found in plots maintained near field capacity, but there was no statistical difference in the averages between treatments. The results from this experiment substantiate conclusions drawn from other studies (Goggans, 1962) that heredity is the dominant influence in determining tracheid length of conifers.

Table 1.--Tracheid lengths according to treatments

Treatment	Range	Average
	- - - - - - - m.m. - - - - - - -	
F.C. in spring, W.P. in summer	2.59-3.57	3.04
W.P. in spring, F.C. in summer	2.59-3.50	3.08
F.C. at all times	2.72-3.81	3.06
When 30 percent moisture used, watered to F.C.	2.75-3.47	3.09
When 60 percent moisture used, watered to F.C.	2.46-3.34	2.90
Control, no treatment	2.80-3.54	3.09

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UNIFORM SEEDLING DENSITY IS IMPORTANT IN HARDWOOD PROGENY TEST NURSERIES

Charles D. Webb[1/]

Efficient progeny testing is an important component of pine tree improvement programs. But, it may be even more important in hardwood improvement programs because the variability of natural stands of hardwoods complicates the process of phenotypic selection. In order for a progeny test to be efficient, either the environment must be held constant from one family to the next, or uncontrollable environmental variation must be accounted for by sound experimental design in the nursery and in field plantings. Usually, efforts are made to do both. Emphasis is placed on selecting uniform nursery beds for growing seedlings and on careful blocking in field plantings.

Additional environmental variation, often not accounted for in the experimental design, can be caused by normal differences in percentage of germination among seedlots. Unless care is taken to plant only sound seed at a constant spacing, or unless seedlings are thinned to a constant density, unequal germination results in variable numbers of seedlings per square foot of nursery bed. And, variable seedling density can affect growth in the field for several years. Although these environmental effects may eventually disappear and true genetic differences in growth rate assert themselves, valuable time is lost. Or, if the test is thinned to form a seedling seed orchard, erroneous selections may result. Hence, I believe that considerable effort is justified in maintaining constant seedling densities among hardwood progenies in the nursery. This belief is based on the following data from a sweetgum seedling grade study and progeny tests in sweetgum and sycamore.

SEEDLING DENSITY AND SEEDLING GRADE

In April 1963, wind-pollinated seed from 15 sweetgum parent trees were sown at Morgan Memorial Nursery[2/] at Byron, Georgia. Soon after germination, the beds were thinned to approximate densities of 10, 20, 30, and 40 seedlings per square foot within each family. The densities could not be held exactly as intended, but a variety of seedling sizes were produced within each family. Seedlings were lifted from 238 plots distributed over all seedling densities and all families; height and root-collar diameter were measured on each seedling.

[1/]Plant Geneticist, Southeastern Forest Experiment Station, Forest Service, U.S.D.A., Forestry Sciences Laboratory, Athens, Georgia.

[2/]Maintained by the Georgia Forestry Commission.

There was a strong, negative relationship between seedling density and root-collar diameter (figure 1). The logarithmic equation fitted to the data ($\log \hat{Y} = 0.9726 - 0.300466 \log X$) accounted for 73 percent of the variation. Seedling height, however, was not related to seedling density.

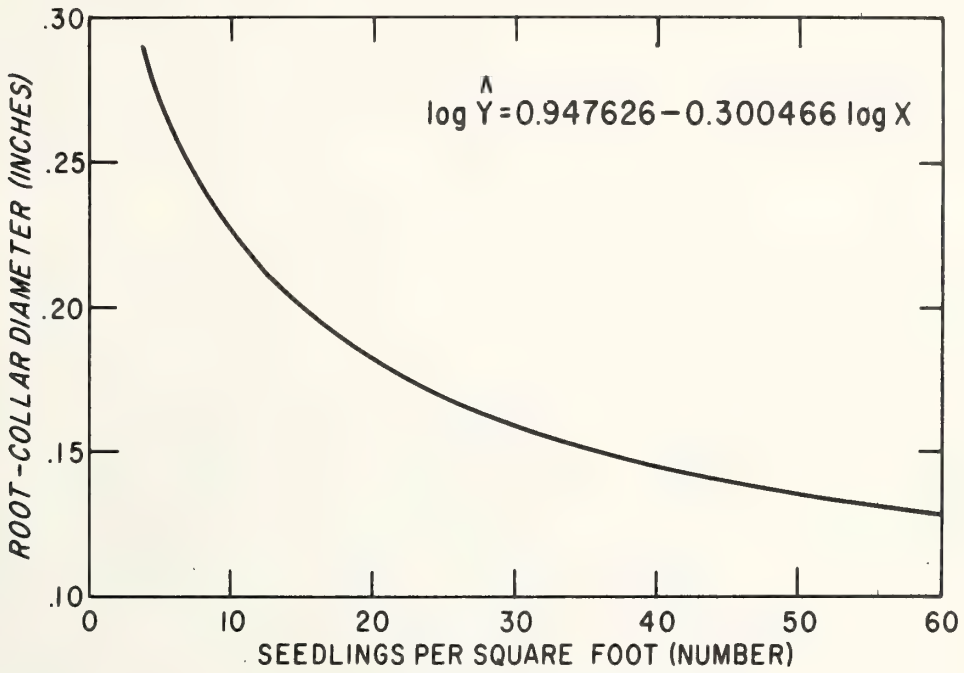

Figure 1.--A strong, negative relationship existed between root-collar diameter and number of seedlings per square foot ($r^2 = 0.73$; d.f. = 236).

Seedlings from 10 of the 15 families were sorted into four groups based on root-collar diameter: less than 3/16 inch, 3/16 to 3/8 inch, 3/8 to 1/2 inch, and greater than 1/2 inch. These seedlings were planted near Athens, Georgia, on a riverbottom site in two replications of a split-plot experiment. The four grades within each family were planted together so that seedlings from the same family were the main plots, and grades within families were the subplots.

From the start, seedlings with larger diameters have grown faster and survived better than those with smaller diameters. After five growing seasons, seedlings from the smallest grade averaged 7.92 feet in height, and those from the largest grade averaged 12.33 feet, a difference of 4.41 feet (figure 2).

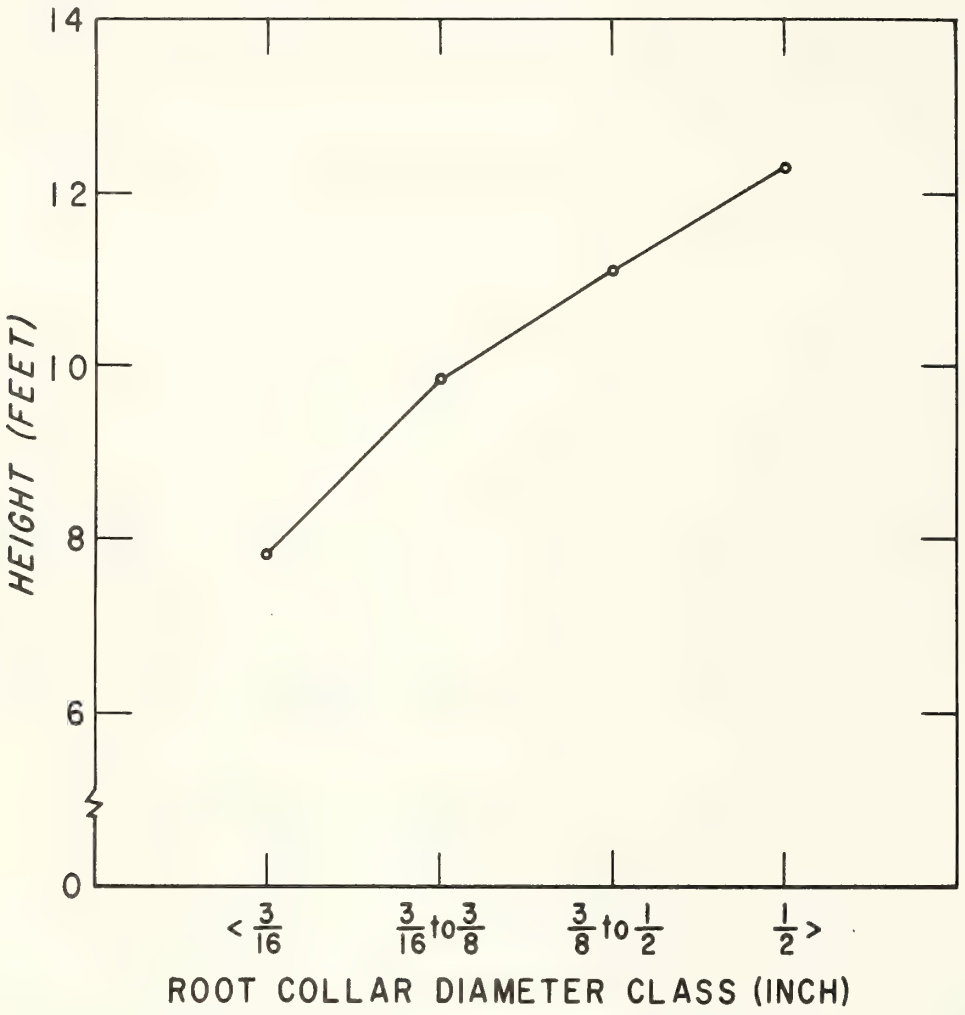

Figure 2.--After five growing seasons in the field, total height was strongly related to initial root-collar diameter of seedlings.

Although part of the differences among grades was due to genetic variation within families, most of the variation was created by thinning the nursery bed to different seedling densities. Therefore, by varying seedling density in the nursery, height growth was affected for five growing seasons, and significant differences will persist for a few more years.

In this plantation, height differences among the 10 families were not statistically significant. This possibly may be related to several factors: either there were no genetic differences among these families, or grading all families to the same seedling sizes removed much of the genetic variation, or the statistical design did not account for the large amount of site variation within the area.

These results on sweetgum agree with numerous reports on a variety of pine and hardwood species (Ike 1962; Johnson and McElwee 1967; Taft 1966; Limstrom et al. 1955; Baron and Schubert 1963; Clark and Phares 1961). The consensus of these authors is that as seedling density in the nursery increases, root-collar diameter decreases. Also, root-collar diameter is a good indicator of seedling growth potential: seedlings with large root collars grow faster after planting than seedlings with small root collars. In shortleaf pine, differences in growth rate related to root-collar diameter have persisted up to 20 years of age (Clark and Phares 1961).

It appears, therefore, that relative growth rate of two families in a progeny test may be altered by the densities at which seedlings were grown in the nursery. That is, if two families of equal genetic potential were grown at widely different nursery bed densities, the seedlings of the family grown at a lower density would have larger root collars and grow faster after transplanting. Conversely, seedlings of the family grown at a higher density would grow more slowly. Therefore, if we permit excessive variation in seedling density in the nursery, we may alter the relative ranking of family averages, confound genetic selection, and cast serious doubts on the reliability of components of genetic variance estimated from the plantation. My experience with sweetgum and sycamore suggests this has, in fact, happened.

A SWEETGUM PROGENY TEST

Seedlings left over from the seedling grade study were planted on a low-lying site in the Upper Coastal Plain in Bleckley County, Georgia. All 15 families were planted in a randomized block design with 12 replications of five-tree row plots. Height was measured annually for the first five growing seasons. Survival has been good, but growth disappointing.

Analyses of variance and F-tests of family effects showed highly significant differences in height in each of the 5 years. On the surface, this appears to be a sensitive F-test with 14 degrees of freedom for families and 154 degrees of freedom for the error term. But a closer look is necessary before any conclusions can be drawn from the data.

When the seedlings were lifted from the nursery, most of them came from plots thinned to 20 seedlings per square foot. In several families, however, it was obvious that actual density was below the intended 20; in these families, seedlings were lifted from plots supposedly thinned to 30 or 40 seedlings per square foot. Later, it was found that there was an alarming variation in actual seedling density among families. On the plots where the seedlings were lifted, density ranged from 8 to 26 seedlings per square foot.

Planting height of the 15 families was not related to the density of the plots from which the seedlings came. However, by the end of the third growing season, a negative trend appeared between family height and seedling density in the nursery. Although the correlation at 3 years of age ($r = -0.507$) was not statistically significant, it was only slightly smaller than the coefficient required for statistical significance (i.e. $r_{.05} = -0.514$, df = 13). At the end of the fourth growing season the correlation had dropped to -0.409, and by the end of the fifth growing season it dropped further to -0.364.

In spite of the weakness of this relationship, the direction of the trend is consistent with the hypothesis based upon the seedling grade study. Of the three tallest families (families 2, 14, and 15), two came from plots with low seedling densities. The three shortest families (families 11, 13, and 17) came from plots with high seedling densities (figure 3).

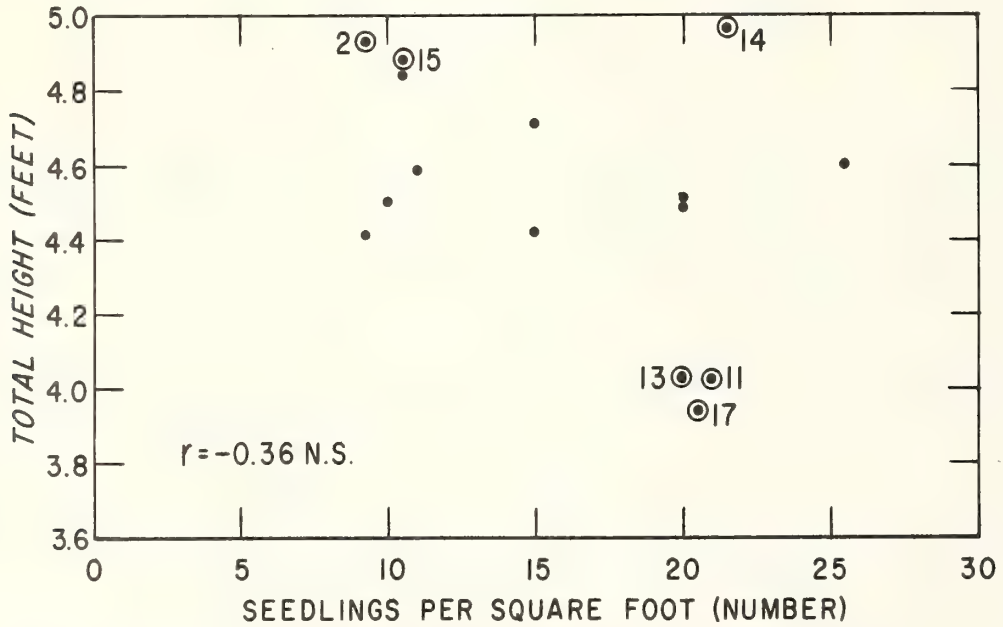

Figure 3.--After five growing seasons in the field, the total height of 15 wind-pollinated progenies was still confounded by variable seedling density in the nursery bed. The numbers beside encircled points identify different families.

Because families 2 and 15 came from low-density plots, I am reluctant to accept them as being genetically superior. However, family 14 came from a high-density plot and has moved from a rank of twelfth in nursery height to first in field height. In time, family 14 may prove to be truly superior. Also, I am reluctant to place any confidence on estimates of genetic variance based on this study. Variance components are sensitive enough as it is without the complications of variable seedling density in the nursery. By the time this plantation reaches 10 years of age, these complications may disappear. Yet, the results of the first 5 years are useless because of the excessive variation in nursery bed density.

A SYCAMORE PROGENY TEST

A similar complication appeared in a sycamore progeny test, but the effects seem to be disappearing quickly. Fifty wind-pollinated families were sown in a nursery at the Harrison Experimental Forest near Gulfport, Mississippi, in May 1966. The parent trees came from five locations along the Chattahoochee River from the mountains of Georgia to west Florida. The seed were sown in the nursery in rows 3 inches apart across beds 48 inches wide; about 1,000 seed were sown in each row. Soon after germination it was obvious that there were large differences among families in number of seedlings per row, a result of variable germination. Laboratory tests on 25 of the families showed germination ranged from 4 to 67 percent.

When the tallest seedlings were about 3 inches tall, all families were thinned to 16 seedlings per square foot. By that time the effects of competition were already apparent. The taller seedlings were concentrated in families with poor germination; and in families having good germination and severe competition, the seedlings were noticeably shorter. Even after being thinned to a uniform density, this difference persisted until the end of the growing season. There was a significant, negative relationship between total nursery height and germination percentage in the laboratory test (figure 4).

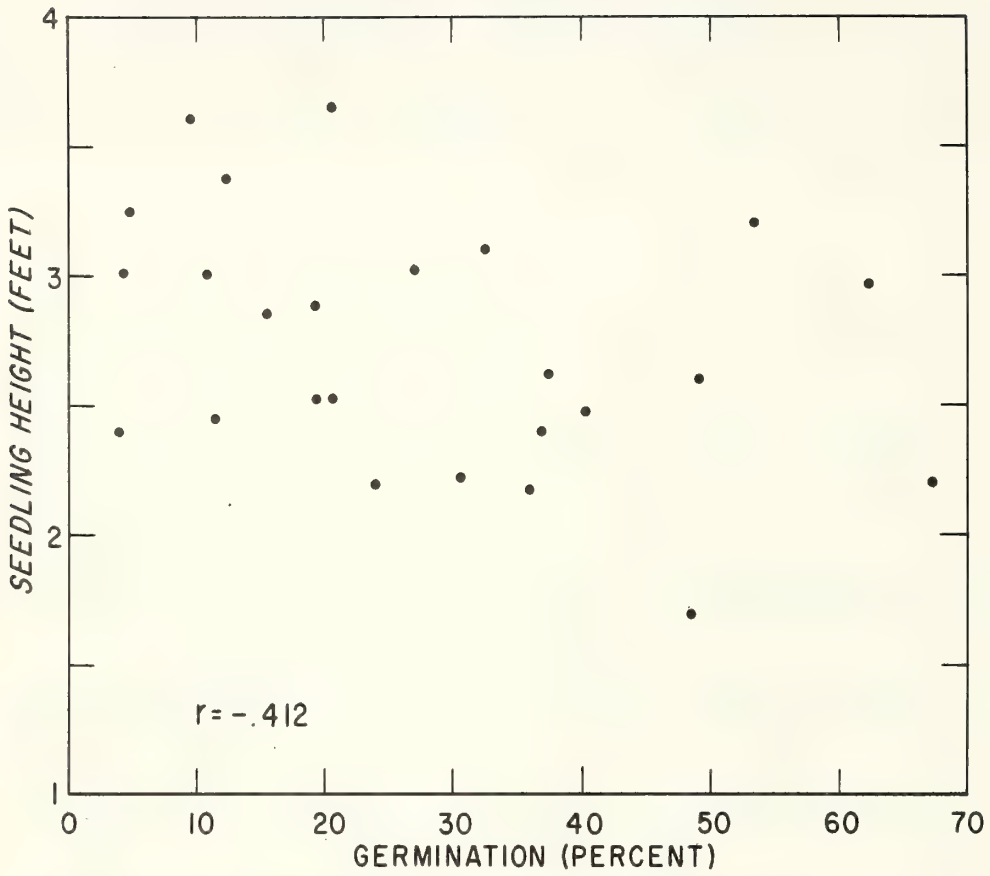

Figure 4.--In sycamore, there was a significant, negative relationship between seed germination percentage in the laboratory and seedling height of 25 wind-pollinated families.

Because the seedlings from this nursery were so large--the tallest was 7 feet tall--their tops were cut off 6 inches above the root collar and the roots, or "stumps," were planted in the field. Survival and growth has been excellent. However, growth of different families during the first season in the field was not correlated with the laboratory germination test. The topping method and planting on a good site may have helped overcome the effects of variable germination and early competition. But, variable germination and thinning too late eliminated any constructive use of the nursery measurements.

DISCUSSION

To some people working with rotation ages of 30 years or longer, these data simply confirm the unreliability of juvenile measurements of growth rate. However, variation in seedling density among progenies in the nursery bed may contribute to this unreliability. The question then becomes: Would controlling nursery bed density give meaning to juvenile measurements and therefore be worth the effort? This may remain a moot question for some time. But if meaningful juvenile-mature correlations are ever found, they will be based on seedlings grown in nurseries where a constant density has been religiously maintained from family to family.

For some hardwoods, especially sycamore, rotation ages as short as 2 to 10 years have been proposed. Tree improvement programs in this context will be vitally concerned with measurements of juvenile growth rate. Therefore, progeny tests designed to detect genetic differences in juvenile growth rate must be planted with seedlings grown at uniform nursery bed densities.

A uniform seedling density can be obtained in at least two ways. With wind-pollinated seed, which are usually cheap and abundant, the bed can be over-sown and thinned soon after germination. Thinning should be done before competition becomes severe in the seedlots having high germination.

The problem of uniform seedling density becomes complicated when control-pollinated seed are used. To use control-pollinated seed most efficiently, single seed will have to be sown in separate containers in a greenhouse or other controlled environment. After the seed have germinated and are established, the container can be transplanted in the nursery bed at the desired spacing. There is a variety of quickly decomposable containers available. Each seems to have certain limitations, but with care problems can be avoided.

The tubeling method, which has been proposed for commericial planting, is a third alternative (Jones 1967). However, tubeling techniques must be perfected before expensive control-pollinated seed are sown in tubes. In some studies, tubelings have grown poorly.

SUMMARY

Progeny testing will be an important part of hardwood tree improvement programs because the variable nature of hardwood stands complicates the process of phenotypic selection. In addition to normal statistical control of environmental variation in progeny tests, seedling density in the nursery bed is an environmental variable that must be held constant from family to family.

If seedling density is allowed to vary from family to family, genetic differences in early growth rate may be covered up, valuable time lost, and erroneous decisions made.

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FERTILIZATION OF AN EIGHT-YEAR-OLD SLASH PINE PLANTATION THINNED FOR SEED PRODUCTION

John E. Morris and Walter L. Beers, Jr.[1/]

In 1968, Buckeye established a 300-acre slash pine (P. elliottii Englm.) seedling seed orchard. To provide an interim seed supply, a nearby eight-year-old slash plantation was converted to a seed production area. A fertilization experiment was initiated in the thinned stand to set up flower induction guidelines for later operational use.

PROCEDURES

Study Area

The flower induction experiment was installed in a 200-acre slash pine plantation thinned five months earlier for seed production. The thinning involved removal of alternate rows, and one-half of the trees in remaining rows. Crop trees were selected on the basis of size, form, and apparent disease resistance. The residual stand contains 200 trees per acre.

Experimental Design

The statistical design was a 4x3x2 NPK factorial with single tree plots. Plots were spaced at least 25 feet apart to reduce inter-plot feeding. Within each replication, stem sizes were purposively held to a one-inch dbh range to decrease variation in tree size.

Fertilizer Application

In May 1967, the 24 treatment combinations of NPK levels shown in table 1 were applied to 15 replications.

In June 1968, five replications were again fertilized with the complete factorial treatments. Each year the fertilizer was hand-distributed within the drip line of the tree crowns. Nutrient sources were NH_4NO_3, superphosphate, and KCL.

1/ Respectively, Research Forester and Associate Staff Manager-Forest Research, The Buckeye Cellulose Corporation, Perry, Fla.

Table 1. Nutrient levels used in the flower induction experiment

Levels	N	P_2O_5	K_2O
	----------Lbs/Tree----------		
1	0	0	0
2	1	2	2
3	2	4	-
4	4	-	-

Data Collection

Total conelet counts were made from a truck-mounted ladder during March of 1968 and 1969.

Statistical Analysis

Conelet counts were transformed by the square root of the count plus one. Analysis of variance was performed to test for significance. An orthogonal set was chosen in advance to contrast nitrogen levels.

The treatment effects on "ripeness to flower" were tested by the chi-square analysis.

RESULTS

Trees with Conelets

The only nutrient significantly affecting "ripeness to flower" was nitrogen. In 1968 and 1969 nitrogen treated trees produced conelets 83 and 87 per cent more often than did the controls. Treatment effects by year are illustrated in figure 1. Chi-square comparisons among the second, third and fourth levels were insignificant both years.

Trees fertilized in 1967 but not in 1968 regressed to inherent conelet status in 1969.

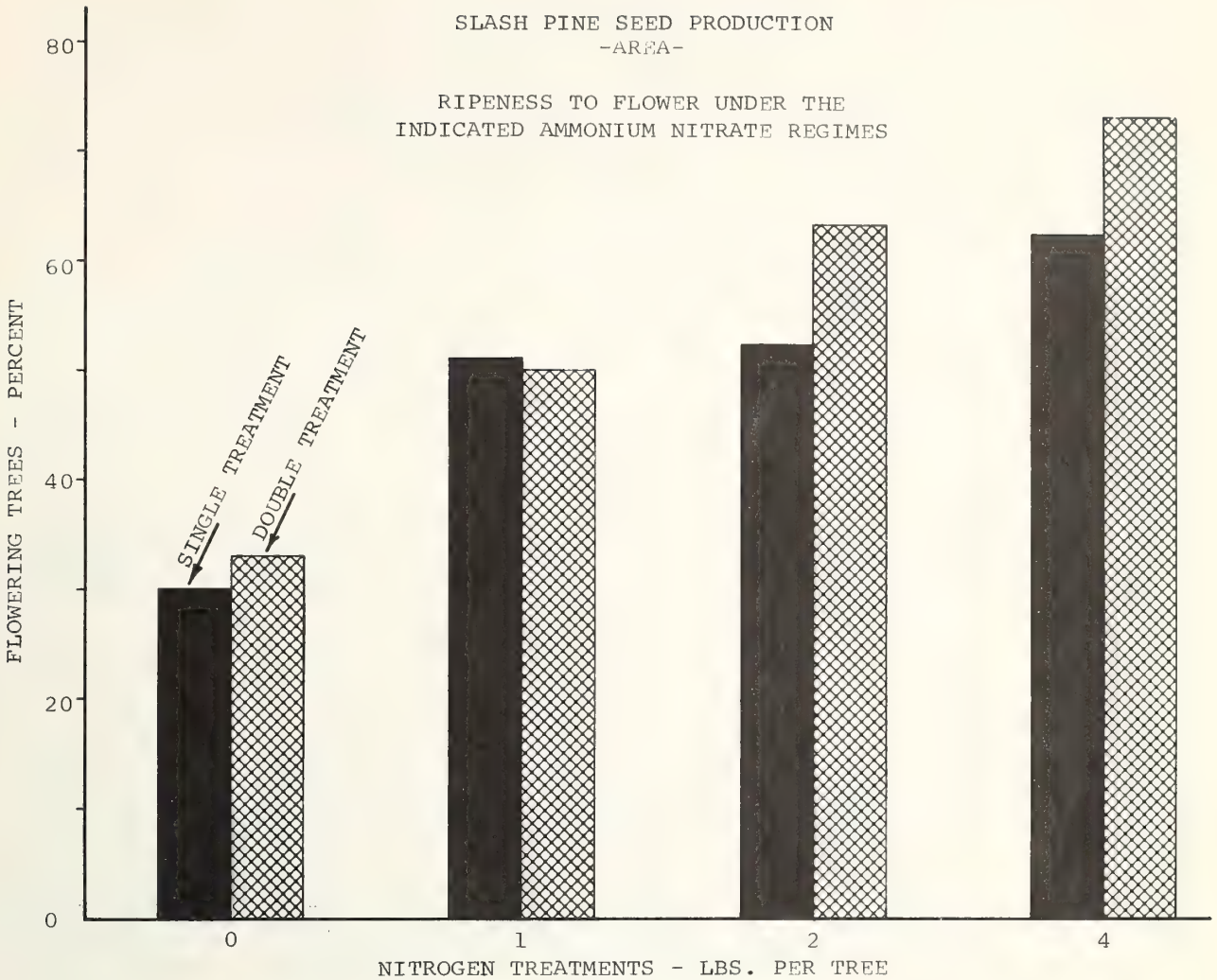

Figure 1. The effect of indicated nitrogen treatments on percentage of trees flowering in a slash pine seed production area.

Conelets per Tree

Nitrogen stimulated the 1968 conelet crop by 87 per cent and the 1969 crop by 540 per cent. Orthogonal comparisons among the second, third and fourth levels were insignificant the first year. In 1969, however, the fourth level induced 109 per cent more conelets than the average of the intermediate levels. Figure 2 illustrates conelet data by treatment and year.

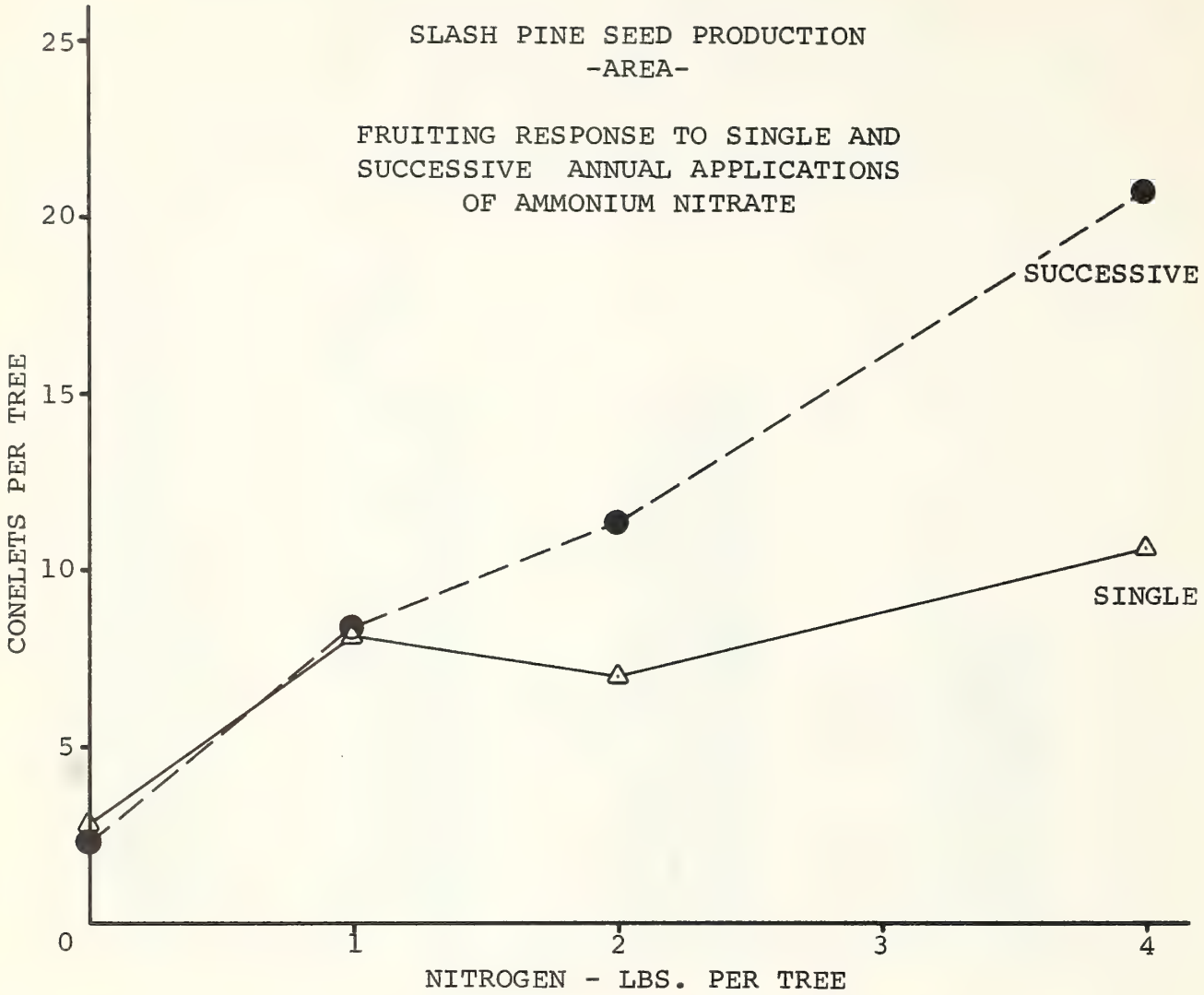

Figure 2. The effect of indicated nitrogen treatments on fruiting in a slash pine seed production area.

The residual flowering effect in 1969 was not meaningful for trees fertilized in 1967 only.

Phosphorus and potassium did not affect flowering.

DISCUSSION

Stimulation of slash pine conelet crops by nitrogen fertilization has been reported previously (Barnes and Bengtson 1968, Hoekstra and Mergen 1957, Shoulders 1968). This study confirms the above, and shows in addition that nitrogen rates as high as 800 pounds per acre may be economically applied to young seed production areas.

Costs of fertilization, cone collection and processing are nearly absorbed in the $5.25 per pound value of unimproved seed. Any genetic gain in volume, then, may be considered as profit. Perry and Wang (1958) calculated an increase in value of approximately $9 per pound for each unit genetic increase. Updating this calculation to reflect current stumpage value, a one per cent increment in volume is now worth about $20. Assuming a one per cent genetic gain, a fertilization expenditure of $30 per acre will return $400 worth of seed per acre. This cost benefit ratio will widen in subsequent years. On this basis, it is clear that flower induction is a profitable operation.

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FEMALE-STROBILUS PRODUCTION IN A SLASH PINE SEED ORCHARD FOLLOWING BRANCH PRUNING

R. J. Varnell[1/]

INTRODUCTION

The utility of pruning to control the size and shape of seed orchard trees has been studied at our laboratory for a number of years. Our first experiment involved nonclonal material, and was not very informative because of the extreme variation in response among trees. More recently, one of our group began a pruning experiment in a slash pine clonal orchard. Female-strobilus production was studied during the first year following pruning; the results are reported here.

METHODS

The work was done in the Forest Service's demonstration seed orchard of high-gum-yielding slash pine, located near Lake City, Florida. The orchard was established in 1957-1958; and a pruning experiment was installed in 1968. The pruning experiment consisted of an unpruned check treatment and three pruning intensities, each replicated over four ramets in each of the nine clones in the orchard.

In late 1968 we began the study reported here. It was based on two to five sample branch systems in each of three ramets in the check treatment and three ramets in the highest intensity pruning treatment in each clone. Ramets were chosen at random from their respective treatments. In each study tree sample branch systems, beginning with the one nearest the ground on the southeast side of the crown, were selected along a vertical line at intervals of approximately 7 feet.

In the highest intensity pruning treatment, all vigorously growing limbs with two or more healthy lateral branches were pruned back to those laterals in March and April 1968.

[1/] Associate Plant Physiologist, Southeastern Forest Experiment Station, Forest Service, U. S. D. A., Naval Stores and Timber Production Laboratory, Olustee, Florida.

In each sample branch system, secondary and tertiary branches with 1968 shoots at least 10 cm. long were selected for measurement, beginning with those nearest the distal tip of the branch system and proceeding basipetally until either five of each branch type had been selected or the supply had been exhausted, whichever came first. The diameter at the midpoint of the first flush of the shoot elongating in 1968 on each branch was recorded in December 1968.

In January 1969, when the strobili initiated in 1968 were in the large twig-bud stage, we recorded the number of (1) foliated branches, (2) branches bearing female strobili only, and (3) female strobili on each bearing branch.

Most data reported here are expressed as the mean value per branch system, because most items were composed of different numbers of branch systems. Exceptions to this will be obvious.

The reliability of the sample to estimate female-strobilus production trends for the entire tree was confirmed by the correlation between the sample data and a whole-tree count of strobili made in April 1969 ($r = 0.83$, $df = 52$).

RESULTS AND DISCUSSION

Branch pruning reduced the average number of branches bearing female strobili in 1969 by 40 percent in seven of the nine clones studied (figure 1). This was due simply to the mechanical reduction of the number of bearing branches. The following tabulation indicates that pruning was concentrated on the female-strobilus producing branch tips:

Item	Nonbearing branches	Bearing branches
	(Number per branch system)	
Unpruned trees	26.9	2.5
Pruned trees	27.4	1.5
Difference (percent)	+1.8	-40.0

How long this effect will persist is unknown, but it is important for at least 1 year following pruning.

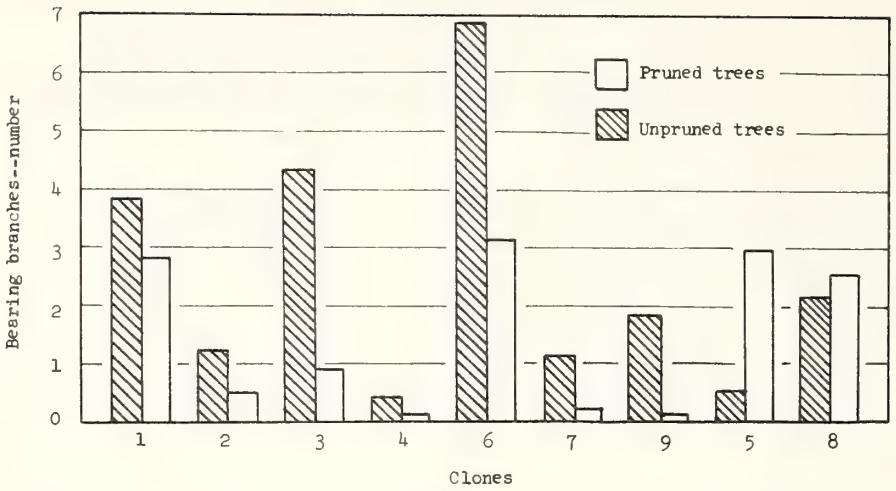

Figure 1.--Effects of pruning on the average number of branches bearing female strobili, per branch system, in 1969.

The number of female strobili per bearing branch, on the other hand, did not vary appreciably between pruned and unpruned trees. The clonal means were as follows:

Clones	Unpruned trees	Pruned trees
1	1.5	1.3
2	1.0	1.0
3	1.3	1.3
4	1.0	1.0
5	1.0	1.2
6	1.0	1.5
7	1.2	1.0
8	1.0	1.3
9	1.0	1.0
Means	1.2	1.3

Thus, the net result at this point was that branch pruning in slash pine decreased female-strobilus production by reducing the number of bearing branches.

As a possible outgrowth of reduced female-strobilus productivity, the percentage of seeds resulting from natural selfing may increase following pruning (Fowler 1965). The proportion of female strobili in the lower 3/5 of the crown (i.e., in the lower 19 feet) was 75 percent in pruned trees; it was only 64 percent in unpruned trees (figure 2). It is in this part of the crown where natural selfing occurs most frequently (Fowler 1965; Franklin 1968). With the greater proportion of female strobili located here in pruned trees, the percentage of seeds resulting from natural selfing should be slightly higher than in unpruned trees.

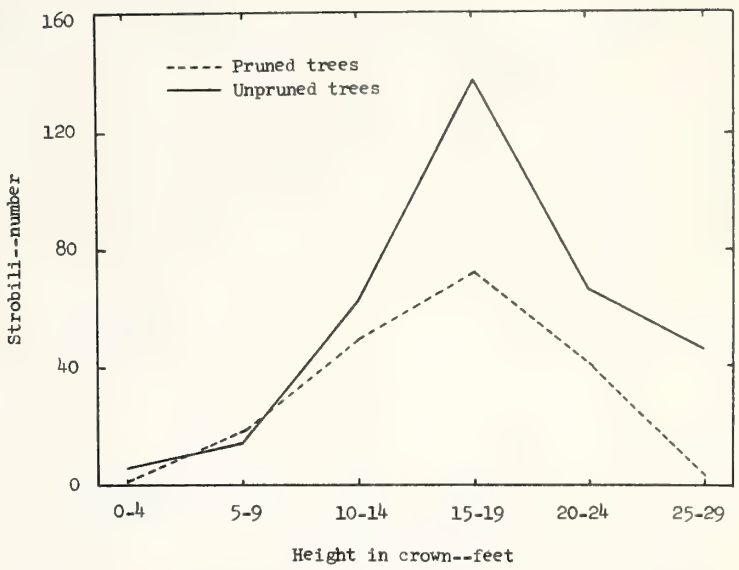

Figure 2.--Effects of pruning on distribution of female strobili within the crown.

Reduced female-strobilus productivity and increased natural selfing may not be lasting effects of branch pruning, however. The increased vigor of branches remaining on pruned trees may eventually compensate for these initial disadvantages.

Branch vigor and the subsequent production of female strobili by both secondary and tertiary branches were correlated in the positive direction in unpruned trees in this study (figure 3). This finding agrees with the relationship documented for many tree species, including slash pine.[2/] Comparisons of this relationship for each branch type (figure 4) revealed that nonbearing secondary branches were 10 percent larger and tertiary branches were 25 percent larger in pruned trees than in unpruned ones. The increased shoot diameter placed the nonbearing branches in pruned trees in the same size range as bearing branches, a result which may have important physiological implications for future female-strobilus production.

[2/] Varnell, R. J. The relationship between vegetative branch growth and subsequent bearing of female strobili in slash pine. 1969. (In preparation for publication.)

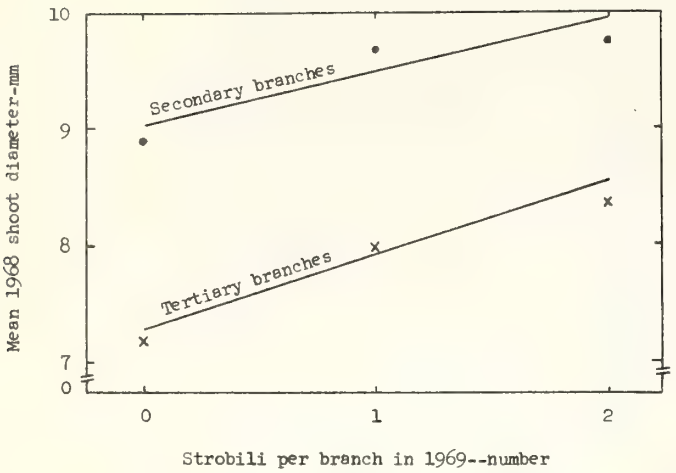

Figure 3.--Relationship between branch vigor and subsequent female-strobilus production in unpruned trees.

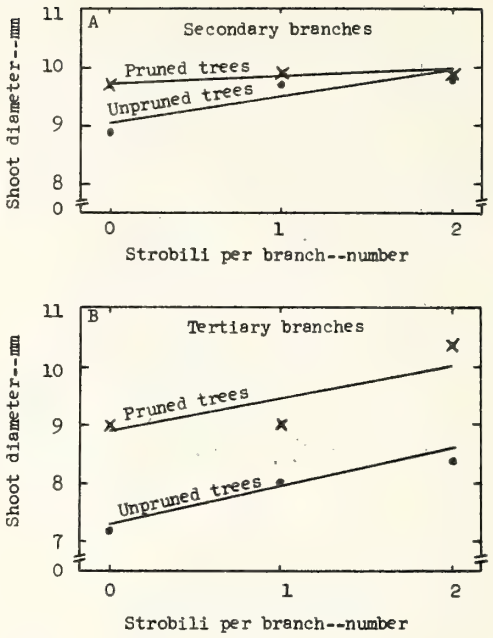

Figure 4.--Relationship of branch vigor and subsequent production of female strobili in pruned and unpruned trees. (Regressions for unpruned trees were significant at the 95 percent level; regressions for pruned trees were not significant at that level.)

First, the larger mean shoot diameters for nonbearing branches in pruned trees suggest that many of these branches may now be vigorous enough to bear female strobili in coming years. Assuming all measured branches in pruned trees will bear female strobili in the future, the productivity from this source could increase as much as eightfold.

Branch type	Number of measured branches	Number of branches which produced female strobili in 1969
Secondary	276	32
Tertiary	295	39
Sums	571	71

Maximum increase = 571/71 = 8.0

Although an increase of this magnitude is not expected, a twofold or threefold increase would be appreciable and would more than compensate for the removal of productive branch tips during pruning.

Second, increased branch vigor following pruning may enhance female-strobilus production by increasing the number of strobili borne per bearing branch. Based on the regressions for unpruned trees as standard relationships between branch vigor and female-strobilus production, secondary branches in pruned trees would be expected to yield 1.6 $\pm$ 0.7 and tertiary branches 3.0 $\pm$ 1.2 strobili per bearing branch (figure 5). The predicted numbers of strobili per bearing branch were not larger statistically than the observed value of 1.3 for secondary and tertiary branches separately in pruned trees. However, they are suggestive of future increased productivity of female strobili by bearing branches.

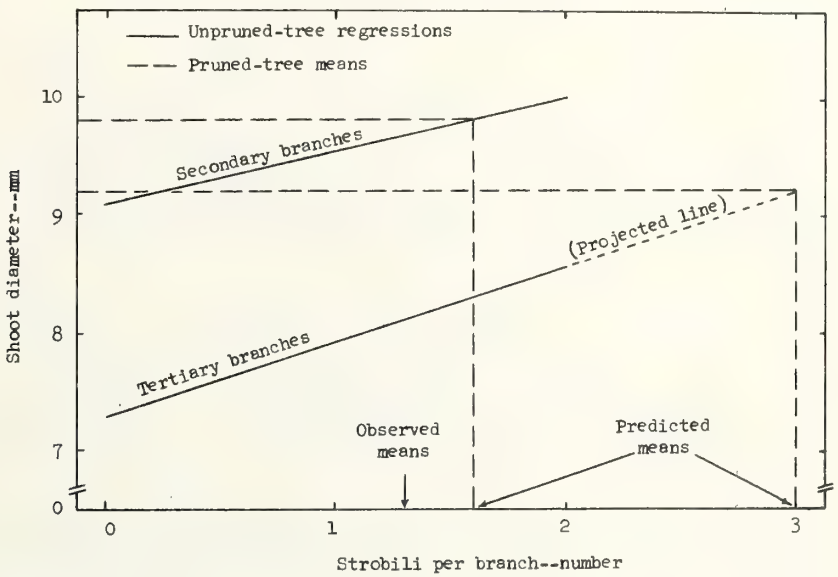

Figure 5.--Predicted mean numbers of 1969 female strobili per bearing secondary and tertiary branches following pruning, based on 1968 mean shoot diameters.

The suggested increases in the number of bearing branches and the number of strobili per bearing branch are speculative. They are discussed merely to illustrate that increased production of female strobili may be expected from increased branch vigor following pruning in slash pine.

Why the vigorous branch development in pruned trees in 1968 did not lead immediately to enhanced production of female strobili is unknown. But, the pattern of branch development from year-to-year in slash pine (see footnote 2) indicates that the vigorous branches in pruned trees probably will maintain their vigor for several years; during this time they can be expected to bear several crops of female strobili.

The possibility of increased female-strobilus production following pruning in slash pine appears to dispute the results of pruning in loblolly pine (van Buijtenen and Brown 1962). The experiments were different: major limbs of loblolly pine were pruned back annually; first growth shoots were pruned one time only in our study with slash pine. Increased production following pruning will be possible only if, after initial treatment, the pruning is discontinued and the potential bearing branches that remain are allowed to develop unmolested.

SUMMARY

The results of this study show that:

1. Branch pruning mechanically reduces the number of branches which subsequently bear female strobili, at least for 1 year.

2. The percentage of seeds resulting from natural selfing may increase following pruning.

3. It is possible that the initial disadvantages of branch pruning may eventually be offset by increased female-strobilus production associated with the increased branch vigor observed following pruning.

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INFLUENCE OF ROOTSTOCK ON FLOWERING IN SHORTLEAF PINE

Ronald C. Schmidtling[1/]

Most of the improvement programs for southern pines involve the establishment of grafted seed orchards from scions of phenotypically superior trees. Horticulturists have long known that rootstocks have profound effects on fruit tree scions, and have applied this knowledge to induce early and prolific flowering and to control tree size (Sax 1958). If rootstock effects exist in pines, they may offer means to increase the productivity of grafted seed orchards.

To examine the possibility that rootstocks affect flowering, I counted the number of flowers on shortleaf grafts in two 7-year-old plantations that included shortleaf, slash, and loblolly pines grafted in all combinations of scion and rootstock. Only the shortleaf-top grafts were included, as it was too late in the year to score for flowering in the other two species.

The scions and rootstocks had been grafted as seedlings and outplanted in 1961 at 11- by 11-foot spacing in randomized designs. The plantations were cultivated and fertilized for the first 5 years, and mowed regularly thereafter. Insecticides were applied to prevent damage by tip moth. In general, the trees were growing under conditions that would be found in most seed orchards.

The original purpose of the plantations was to test the effect of rootstock on height growth, but after 5 years there were no significant height differences in the shortleaf-top trees (Allen 1967). When these tops were scored for flowering in the spring of 1968, they averaged 20 feet in height. Flowering had been observed as early as the fourth year, but no counts had been made.

The shortleaf scions flowered best on loblolly rootstocks: 93 percent of the tops had flowers, and the average number of flowers per top was 60.1. Performance was poorest on slash rootstocks, with 47 percent flowering and an average of 32.8 flowers per tree. Tops on shortleaf rootstocks were intermediate, with 67 percent flowering and an average of 45.2 flowers per tree.

The range in number of flowers per tree was so great--from 0 to 380--that it was not possible to determine if averages for the three rootstocks differed significantly. The differences in numbers of trees flowering, however, were significant (table 1).

The log-likelihood ratio test (Woolf 1957) for a 2×3 contingency table gave a chi-square value of 7.548 with two degrees of freedom. The probability of getting this chi-square value by chance alone is less than 0.025.

1/ The author is stationed at the Institute of Forest Genetics, Southern Forest Experiment Station, USDA Forest Service, Gulfport, Mississippi.

Table 1.--Flowering response of shortleaf pine scions, after 7 years in the field

Rootstock	Trees with flowers	Trees without flowers
	Number	Number
Shortleaf	6	3
Slash	7	8
Loblolly	13	1

$\chi^2 = 7.548^*$ $0.025 > p > 0.02$

If we consider the number of trees showing any evidence of flowering, including not only flowers but conelets and old cones as well, the results are consistent with the flowering data and still significant (table 2). All of the shortleaf on loblolly rootstocks showed some evidence of reproduction, whereas only 60 percent of those on slash rootstocks and 78 percent of those on shortleaf rootstocks did.

Table 2.--Cumulative reproductive response of shortleaf grafts, after 7 years in the field

Rootstock	Trees with flowers, conelets, or cones	Trees with no evidence of reproduction
	Number	Number
Shortleaf	7	2
Slash	9	6
Loblolly	14	0

$\chi^2 = 6.779^*$ $0.05 > p > 0.025$

Since the plantations were small and not designed to test flowering, it would be premature to recommend loblolly rootstocks for shortleaf pine seed orchards on the basis of these results. The differences are large enough, however, to warrant further work, and a systematic search for a standard rootstock to be used with each pine species might be profitable.

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COMPARING GRAFTING TECHNIQUES FOR BLACK WALNUT

William J. Lowe and Walter F. Beineke [1/]

The increasing demand for black walnut timber in recent years has caused interest in planting black walnut. A source of superior seed is needed to obtain the best growth and quality possible from these plantings. Techniques are needed to insure that selected clones can be propagated in seed orchards for the production of the required seed. In addition, high quality black walnut is rapidly being cut, and the gene pool drastically narrowed. Therefore, there is great interest in preserving superior selections by grafting before they are cut.

The object of this study was to compare five different propagation techniques in an effort to determine which methods were suitable for use in the establishment of black walnut seed orchards.

MATERIALS AND METHODS

Scion was collected by shooting branches from the selected phenotypes between March 13 and March 26, 1968. As soon as the scion was collected in the field it was placed in polyethylene bags and packed in moist sphagnum moss. Once in the laboratory the cut ends of the scion were dipped in paraffin to prevent drying. The scion with some moist moss was then sealed in polyethylene bags and stored at a temperature of 34° to 36° F. Scion was stored until June without having any deleterious effects.

Care should be taken during storage to insure that the scion is not too wet or dry. Hartmann and Kester (1961) stressed that the moss should be barely moist because the scion is more liable to be damaged by being too wet, due to fungal development, than by being too dry. When the scion is being stored for a prolonged period, it should be checked occasionally for moisture loss.

Sitton (1931) and McKay (1966) stressed the use of large caliper scionwood (3/8 to 5/8 in.) for best results in grafting. Whenever possible scionwood of this size was collected. However, on may selections it was impossible to obtain wood of this diameter. Scionwood 1/4 inch in diameter was used for grafting without encountering undue loss. The basal portion of the current years growth or 2-year-old wood produce the best scion. It was preferred to make the graft union on the 2-year-old wood and have the buds present from the first-year wood.

[1/] Respectively, Graduate Research Assistant and Assistant Professor of Forestry, Department of Forestry and Conservation, Purdue University, Lafayette, Indiana.

Tops of the root stocks were severed 10 to 14 days before grafting. This allowed ample time for the stocks to bleed and thus reduce graft failure due to sap flow. At the time of grafting, the stocks were cut off again to expose live wood.

After the scion or bud was in place, it was wrapped with a rubber strip (1/4 in. x 8 in.) and painted with paraffin. The paraffin covered the entire piece of scion and all cut surfaces and thus, helped to prevent the scion from drying out before callusing and union had occurred.

Adventitious shoots which developed below the graft point were removed every few days to force growth on the graft. On some grafts the buds did not begin growth until after these adventitious shoots were removed.

Grafts should be staked for support during the first two years to reduce strain placed upon the graft union by the action of the wind.

Grafting methods used were as follows: bark inlay, cleft grafting, whip grafting, T-budding, and patch budding. Propagation techniques with the exception of patch budding were performed between April 9 and May 21, 1968, while patch budding was done on August 28, 1968.

After active growth of the stock had started, the bark inlay was performed as follows:

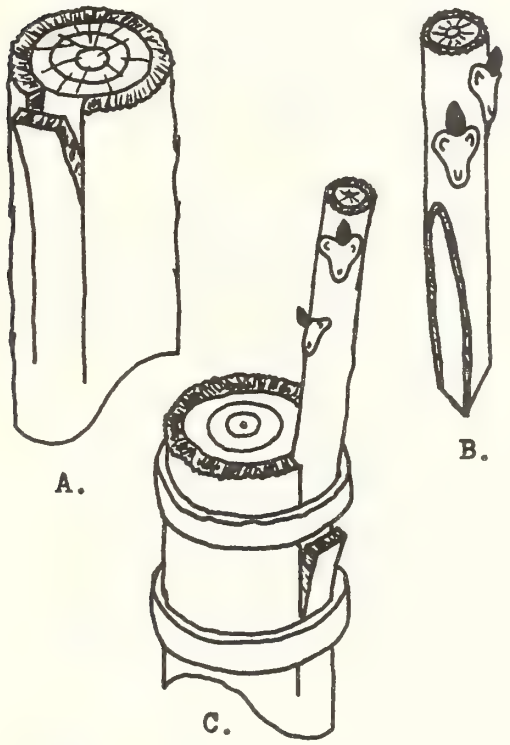
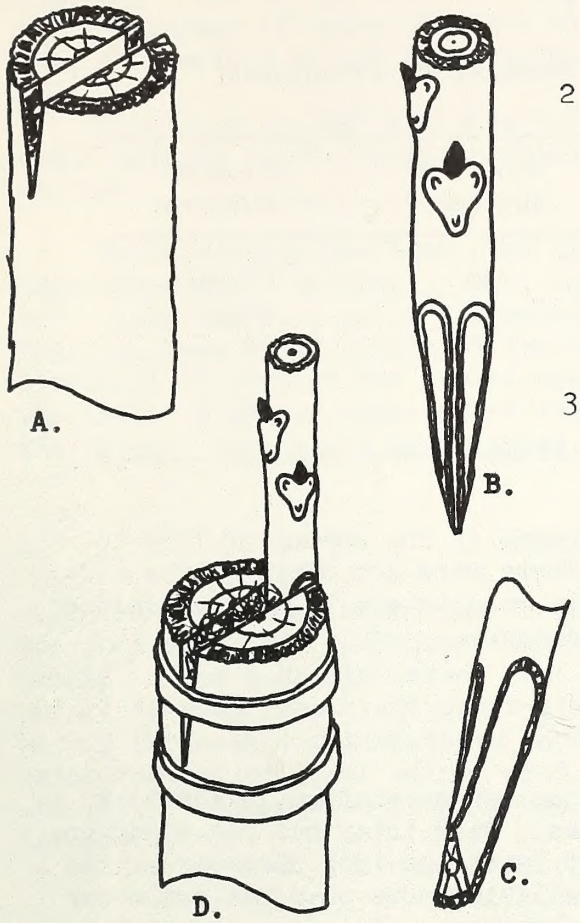


Fig. 1 - Bark Inlay Graft
A, Stock; B, Prepared Scion;
C, Completed Graft.

1. Preparation of the Stock (Fig. 1A)
   a. Vertical, parallel cuts (1 to 2 inches long) were made through the bark of the stock. The distance between these cuts was equal to the width of the scion.
2. Preparation of the Scion (Fig. 1B)
   a. A sloping cut (1 to 2 inches long) was made on one side.
   b. A second cut (1/2 inches long) was made on the opposite side.
3. Completion of the Graft (Fig. 1C)
   a. Bark was peeled from the stock and the scion inserted in the slot.
   b. The top 2/3 of the bark flap was removed.
   c. The scion was tied in place with a rubber strip.
   d. The grafted stub and scion were waxed.
   e. Occasionally checks were made to replace the rubber strips as they deteriorated.
   f. Adventitious shoots were removed from the stock as they developed.

Before active growth of the root stock had started, the cleft graft was performed as follows:



1. Preparation of the Stock (Fig. 2A)
   a. The stock was split for a length of 2 to 3 inches.
2. Preparation of the Scion (Fig. 2B and C)
   a. A sloping cut (1 to 2 inches long) was made on one side.
   b. A second sloping cut the same length was made on the opposite side in a manner that formed a wedge, which is slightly thicker on the outer edge of the scion than it is on the inner edge.
3. Completion of the Graft (Fig. 2D)
   a. The split in the stock was held open by a wedge.
   b. Insert the scion in the stock with the thicker edge to the outside of the stock. The cambiums of the stock and scion must align.
   c. The wedge was withdrawn.
   d. The stock was wrapped with a rubber strip and soft paper was placed in the remaining portion of the cleft.
   e. The grafted stub and scion were waxed.
   f. Occasional checks were made to replace rubber strips as they deteriorated.
   g. The adventitious shoots were removed from the stock as they developed.

Fig. 2 - Cleft Graft.
A, Stock; B, Side View of Scion; C, End View of Scion; D, Completed Graft.

Whip grafting was performed before the root stock had initiated growth while the T-budding was performed after the bark on the root stock had started to slip. Both techniques were accomplished as described in Hartmann and Kester (1961) with the exception that a callus stimulate (indolebutyric acid and naphthalene acetic acid) was used with the whip grafts.

Patch budding was done on August 28, 1969, using buds that were collected on August 26, from the current years growth. The patches were cut on the root stocks 14 days before the actual budding operation. The procedure described in Hartmann and Kester (1961) was followed.

RESULTS

The number of grafts performed and the percentage of successful grafts per technique are shown in Table 1.

Table 1. Results of Different Propagation Techniques

Method	Number Attempted	Number of Successes	Percent of Success
Inlay	36	30	83.3%
Cleft	25	12	48.0
Whip	37	0	0
T-Bud	37	0	0
Patch Bud	86	0	0

The cleft graft and bark inlay were used in the spring of 1969 to establish a black walnut seed orchard. There were 209 cleft grafts and 98 bark inlays performed. The preliminary results are 71.8% success for the cleft grafts and 76.8% for the bark inlays.

DISCUSSION

The bark inlay was the fastest and easiest to perform in addition to having the greatest percentage of takes. Bark inlay has the disadvantage of requiring root stocks that are at least one-inch diameter at the grafting point. If larger stocks are available, more than one scion can be grafted to each stock.

Cleft grafting is both relatively easy and fast and does not require one-inch diameter root stocks. After the scion was in place and wrapped, absorbent paper was placed in the remaining portion of the cleft to absorb excess sap.

On March 18, 1969 three cleft grafts were made using scion that was collected during November, 1968, when a superior selection was cut. These grafts were placed in a growth chamber which was set for a 12-hour daylight photoperiod with day and night temperatures of 60° and 45° F, respectively. By March 28, the day length had been gradually increased to 15 hours while the day and night temperatures had been increased to 80° and 65° F, respectively. Relative humidity was maintained between 80 and 100 percent. All three grafts were successful which demonstrates the importance of high humidity and moderate temperatures in callus formation. Growth chamber grafting is of value when a selection is cut before normal scion collection season. However, in this one case scion was successfully stored from November until field grafting in May.

A callus stimulant was used on the whip grafts. The stimulant was carried in an alcohol base, and it is thought that the alcohol killed the cambial cells which could account for the lack of success with whip grafting. Due to the time involved in performing the whip graft and the percentage of takes obtained with other techniques, it is believed that this method is not satisfactory for field use with black walnut.

T-budding is fast and easy but it appears that the bark of even small walnuts is too thick to obtain a good fit around the margins of the bud.

Patch budding has been used by many workers, but the results have been uncertain. By April, 1969, many of the patches had died and fallen off. Apparently, a patch is needed that is free of extra leaf scars. This requires rapid growth of the budwood, and budwood of this type is difficult to collect due to its absence or its position in the crown of the tree. Also, we experienced difficulty in keeping the bud trace with the patch. This could have caused the total mortality which we experienced.

CONCLUSIONS

The bark inlay technique is the most appropriate method to use when the root stock has sufficient diameter (greater than 1 inch at grafting point). When a smaller-sized root stock (less than 1 inch at grafting point) is used, the cleft graft gives satisfactory results. Either method produces a satisfactory percentage of successes to be used in the establishment of black walnut seed orchards. Whip grafting, T-budding, and patch budding were totally unsuccessful under the conditions of this investigation.

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